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A TIME VARIABLE MODEL OF EARTH'S ALBEDO

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Ann Arbor, Michigan 48109

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A Time Variable Model of Earth's Albedo

Final Report

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Hampton, VA 23665

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## Abstract

A time variable model of earth's albedo has been prepared for use in climate studies and as an aid to the interpretation of satellite earth radiation budget data. The Fortran computer program is assembled in modular form, so that improvements can be made to any module independently of the rest. Features of the model include: a  $10^{\circ}$  latitude- $10^{\circ}$  longitude grid for numerical integration, surface albedo specified at one month intervals, calculation of zenith angle effect for surface albedo and of the additional effect of the atmosphere on the albedo. Percent cloud cover is specified for 29 different climatological cloud type regions at 8 times of the day for 12 months of the year. Cloud albedos have been specified for each of the cloud climatological types. Diurnal and monthly variations of this model are described and results are compared with the model of Ellis and Vonder Haar which is based on satellite measurements.

A computer program has also been written for use in studying the sampling effects in satellite radiation budget measurements. An example of the results of calculations with this program are compared with a previous study of the sampling effects. This program for satellite orbit characteristics is to be combined with the time-variable albedo model for further study of the sampling problem.

## I. Introduction

The program of research to be described in this report, has the objective of producing a time variable model of earth's albedo suitable for possible use in climate studies. Such a model could also be an aid to the interpretation of satellite earth radiation budget data and could be used for other applications involving solar radiation. One such application would be the prediction of regional or local incident solar energy, using satellite albedo measurements.

Recent earth's albedo models described in the literature include a zonal average albedo model based on satellite earth radiation budget measurements (Ellis and Vonder Haar, 1976). This model, based on 29 months of satellite radiation budget measurements taken intermittently over the period 1964 through 1971, presents average data for 10 degree latitude zones for 12 mean months, 4 mean seasons and an average year.

Another study of radiation and energy budgets of the earth presents two monthly zonal average models of earth's albedo, one (model A) based on surface observations of cloud cover and the other, (model B) based on satellite observations of cloud cover (Hoyt, 1976). Both of these models present average data for 5 degree latitude zones for 4 seasons and an annual mean. In this study the model B cloud cover was obtained from the model A cloud cover by applying systematic corrections to the model A data according to suggestions by Malberg (1973) who had compared ground based observations of total cloud cover with simultaneous 0.5 km resolution satellite observations.

The time variable model described in this report is an initial attempt to specify the nature of time varying earth's albedo. The problem was approached as "open-ended"; to be improved by further study and modification. It is constructed in modular form. Each module can be modified and improved

separately from the rest to produce a net improvement in the whole. The individual modules are considered to be:

1. A  $10^{\circ}$  latitude -  $10^{\circ}$  longitude grid, which defines regions of the earth for which albedo is specified. A next step improvement would possibly be a  $5^{\circ}$  latitude -  $5^{\circ}$  longitude grid, which however will increase the cost of computer calculations by a factor of 4.
2. Surface albedo, which has been specified for each area element of the grid, initially for each season of the year, and then, for each month of the year. Ideally the next version of the model would include bi-weekly or weekly variations in surface albedo.
3. Zenith angle effect for surface albedo: Three zenith angle functions for surface features have been used, one each for land areas, ocean areas and snow/ice areas. An improvement would be to specify different functions for significantly different earth surface features. That is, one could differentiate between desert areas and mountain areas, etc.
4. The additional effect of the atmosphere on earth's albedo: The formulation used in this model for the albedo of the earth-atmosphere system uses the same equations for land, ocean and snow/ice regions. It is possible that different functions should be used for different earth surface features.
5. Climatological cloud cover type regions: Percent cloud cover has been specified for 29 different climatological cloud type regions based on the work of Sherr, et al. (1968). Their cloud type regions were modified slightly to fit the  $10^{\circ}$  -  $10^{\circ}$  grid of this model. The  $5^{\circ}$ - $5^{\circ}$  grid would improve this module slightly. Also an improvement in percent cloud cover distributions is likely when more satellite data is analyzed.
6. Cloud albedo: Cloud albedos have been estimated crudely. A significant

improvement in the model can be made by application of satellite data for cloud albedo.

7. Diurnal Variations: Calculations have been made for 8 different times in a day, 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00 and 21:00 (GMT), corresponding to sub-solar longitudes of 0.0, 45.0, 90.0 . . . 315.0, respectively. A finer time interval increment, 1 hr, would show more of the detail of time variability of earth's albedo.

The effect of the atmosphere above the clouds has been neglected.

Section two of the report, which follows, specifies the detailed characteristics of each of the modules described above. The calculation procedure is described in Section Three. The initial phase of the application of the model to earth radiation budget measurements from satellites is summarized in Section Four. Section Five contains conclusions and recommendations for further work on this model.

## 2. Time Variable Albedo Model

### 2.1 Surface Albedo

The albedo model described herein is designed on a  $10^\circ$  latitude by  $10^\circ$  longitude grid on the surface of the earth. The surface albedo of each  $10^\circ \times 10^\circ$  element was specified initially for each season of the year using the data of Hummel and Reck (1979). In a second version of the model, surface albedo values were specified for each month of the year, using the seasonal values of Hummel and Reck adjusted by reference to the monthly zonal averages of Robock (1979). This arbitrary procedure yields annual zonal surface albedo values intermediate between Robock's and Hummel and Reck's.

More specifically each element of the  $10^\circ \times 10^\circ$  grid of the earth was assigned values of surface albedo  $A(I,J,K)$  where:

$$I = \begin{cases} 1, 2, \dots, 4 \\ \text{or} \\ 1, 2, \dots, 12 \end{cases} \quad \begin{array}{l} \text{(season of the year, starting with winter)} \\ \text{(month of the year, starting with Jan.)} \end{array}$$

$$J = 1, 2, \dots, 36 \quad \text{(longitude index)}$$

$$K = 1, 2, \dots, 18 \quad \text{(latitude index)}$$

The correspondence between longitude index and longitude was taken as:

$$\begin{array}{ccccccc} J & = & 1 & 2 & 3 & & 36 \\ \text{Longitude} & = & 0^\circ-10^\circ & 10^\circ-20^\circ & 20^\circ-30^\circ & & 350^\circ-360^\circ \end{array}$$

with longitude measured west from the Greenwich meridian.

The latitude index correspondence with latitude is:

$$\begin{array}{ccccccc} K & = & 1 & 2 & 3 & \dots & 9 & 10 & \dots & 18 \\ \text{Latitude} & = & 90-80\text{N} & 80-70\text{N} & 70-60\text{N} & & 10-0\text{N} & 0-10\text{S} & & 80-90\text{S} \end{array}$$

that is from the north polar regions southward with increasing K.

The surface albedo data for each month of the year for the second version of the model is shown in Tables A-1 to A-12 in Appendix A of this report.

These values are assumed to represent surface albedo values averaged over the range of solar zenith angles appropriate for the given month and latitude.

## 2.2 Zenith Angle Effect for Surface Albedo

Time variability was restored to the monthly surface albedo data described above by use of the three solar zenith angle functions of Larson and Barkstrom (1977) for land, ocean and snow (and/or ice) areas. Thus the solar zenith angle dependent albedo values become:

For land:

$$[A(I,J,K) 0.458(1 - \cos(\theta) \ln(1 + \frac{1}{\cos(\theta)})) \frac{1}{0.1874}] \quad (1)$$

where:  $\theta$  is the solar zenith angle

$\ln$  is the natural logarithm

0.1874 is the value of the function averaged over all zenith angles from 0 to 90°.

For ocean:

$$\left[ A(I,J,K) \left( .03 + \frac{.630}{1 + \left( \frac{1.47 - TH}{.15} \right)^2} \right) \frac{1}{0.1065} \right] \quad (2)$$

where: TH is the solar zenith angle in radians

.1065 is the value of the function averaged over all zenith angles from 0 to 90°

For snow (or ice):

$$[A(I,J,K) 0.797(1 - 0.176 \cos(\theta)) \frac{1}{0.7035}] \quad (3)$$

where:  $\theta$  is the solar zenith angle

.7035 is the value of the function averaged over all zenith angles from 0 to 90°

The three functions described above are shown in Figure 1.

It should be noted that the factors 0.1874, 0.1065 and 0.7035 are correct only for those latitudes and times of the year for which the sun indeed traverses the sky through the zenith angle range of 0 to 90°. For most latitudes and times of the year the sun's zenith angle changes from 90° to some minimum angle greater



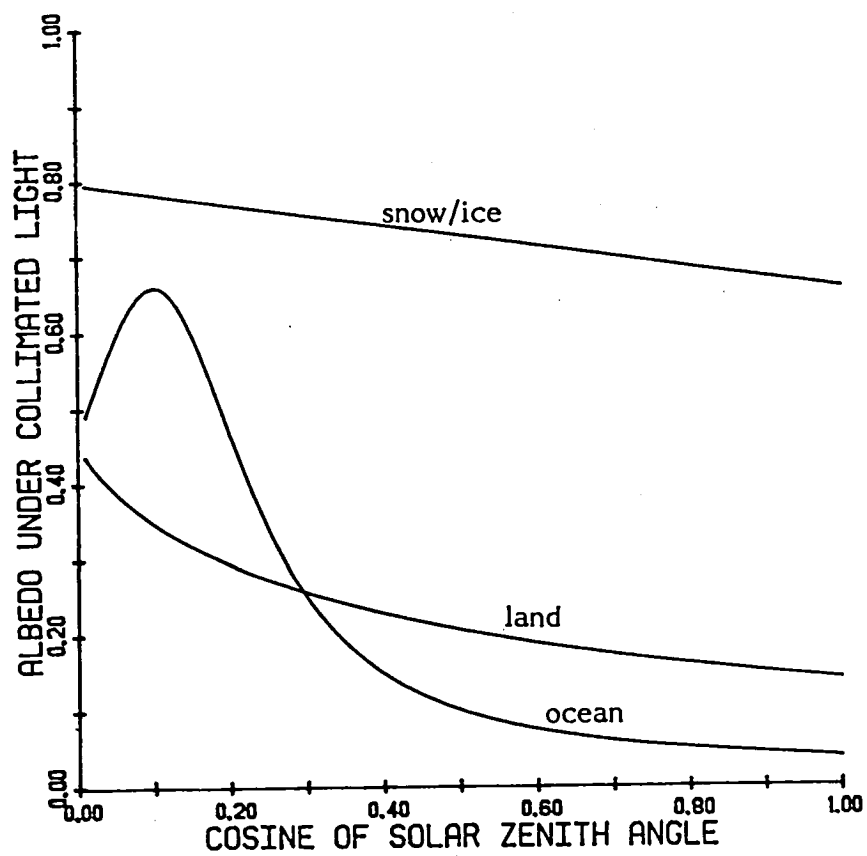


Figure 1 Zenith angle dependence of surface albedo (after Larson and Barkstrom, 1977).

than  $0^\circ$  and thus the factors used are incorrect.

The above technique, although incorrect, has been adopted initially as an approximation because it is easy to implement. The more exact calculation which is more difficult to implement is a refinement which will be added to the program later on.

### 2.3 Albedo of the Earth-Atmosphere System

For cloud free sky conditions the combined effects of the earth-atmosphere system are modelled by functions described by Nack and Curran (1978). Thus the albedo combining surface and atmospheric effects becomes:

$$\left\{ [ \quad ] M_s(\theta) + A_s(\theta) \right\} \quad (4)$$

where  $[ \quad ]$  is given by equation 1, 2 or 3 above, as appropriate, and:

$$M_s = .7213 - 2.180 \cdot 10^{-9} \theta^4 + 4.94 \cdot 10^{-13} \theta^6 \quad (5)$$

$$A_s = .0483 + 1.087 \cdot 10^{-5} \theta^2 - 2.219 \cdot 10^{-9} \theta + 6.776 \cdot 10^{-13} \theta^6 \quad (6)$$

Figure 2 shows the resultant albedo at the top of the cloud free atmosphere as a function of surface albedo for several solar zenith angles. Note that the albedo of the surface-atmosphere system is greater than the surface albedo for low surface albedos and less than the surface albedo for large values of surface albedo.

### 2.4 Climatological Cloud Cover Data

The world-wide cloud cover distributions of Sherr, Glasen, Barnes and Willand (1968) are used in this time variable model. These authors prepared probability distributions of world-wide cloud cover for use in the simulation of

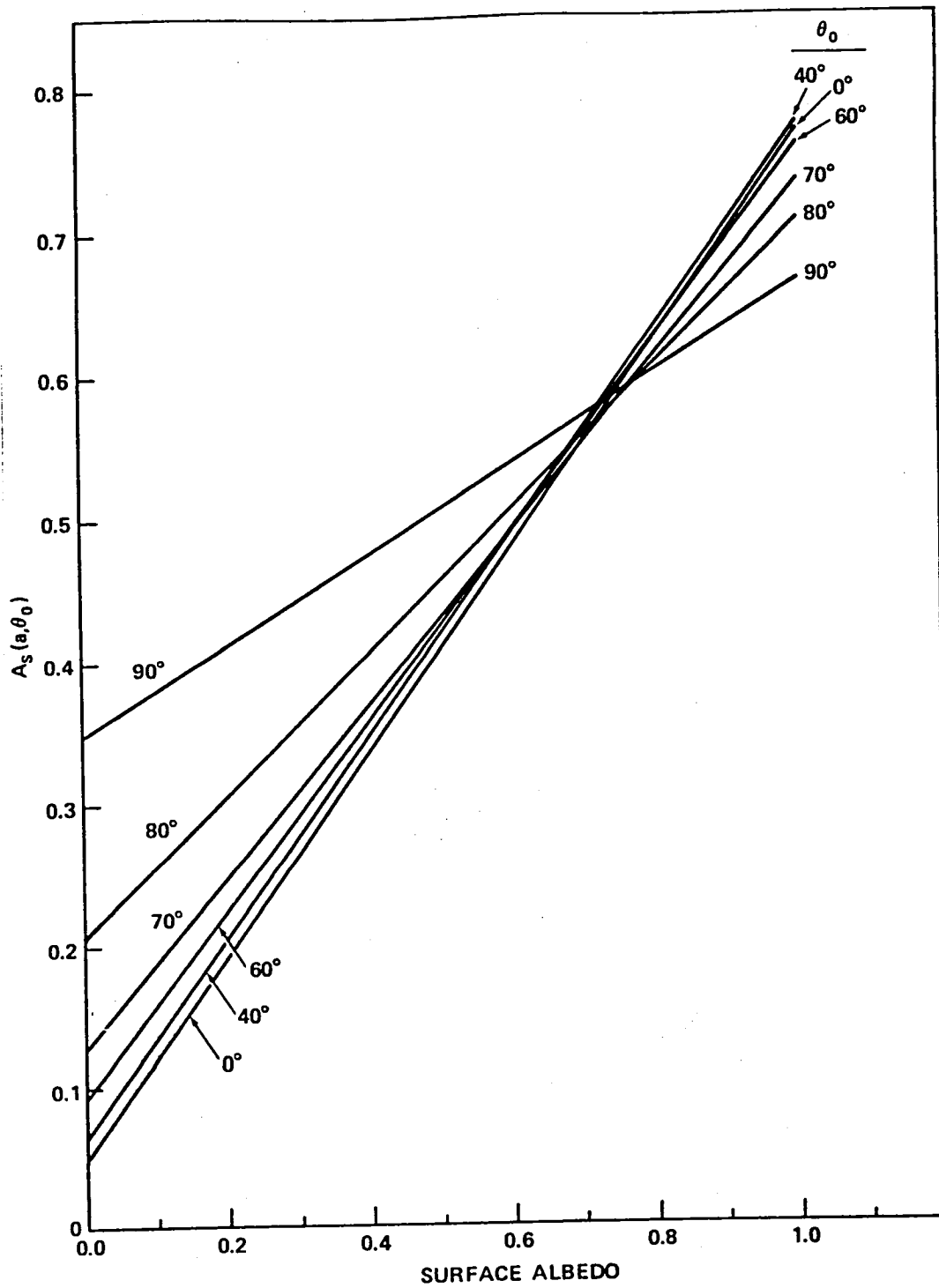


Figure 2 Albedo at the Top of the Cloud-free Atmosphere as a Function of Surface Albedo, for Several Solar Zenith Angles (after Nack and Curran, 1978).

earth-oriented observations from space. Five cloud categories, including one for clear skies and one for overcast skies, are given for 29 cloud climatological regions, for eight times of the day and for each month of the year.

Each cloud category refers to a range of percent cloud cover as indicated below:

<u>Category</u>	<u>Cloud Cover in Tenths</u>
1	0
2	1, 2, 3
3	4, 5
4	6, 7, 8, 9
5	10

The 29 cloud climatic regions are shown in Figure 3. Satellite data were used to establish the homogeneity of the regions. Within each region cloud cover frequency data were obtained from a representative station usually having at least 10 years of observations.

Since the cloud climatic region areas of Sherr, et al., did not begin and end on the  $10^{\circ} \times 10^{\circ}$  latitude-longitude lines of our model, his map areas were modified (stretched or contracted slightly) to fit our model. Table 1 shows the cloud climate regions used for each  $10^{\circ} \times 10^{\circ}$  area in our model.

Sherr's general description of the nature of the clouds in each cloud climatic region is given in Table 2. For each cloud region, probability distributions of the five possible cloud amount categories are given for each of the 12 months of the year at eight local times during the day: 01:00, 04:00, 07:00, 10:00, 13:00, 16:00, 19:00 and 22:00.

From the probability distribution data given by Sherr, the percent cloud cover was calculated for each cloud climate region as a function of the eight different local times of the day for each month of the year. The percent cloud cover data used in this model is given in the Tables B-1 to B-96 in Appendix B. Each table shows the world-wide percent cloud cover distribution for a given

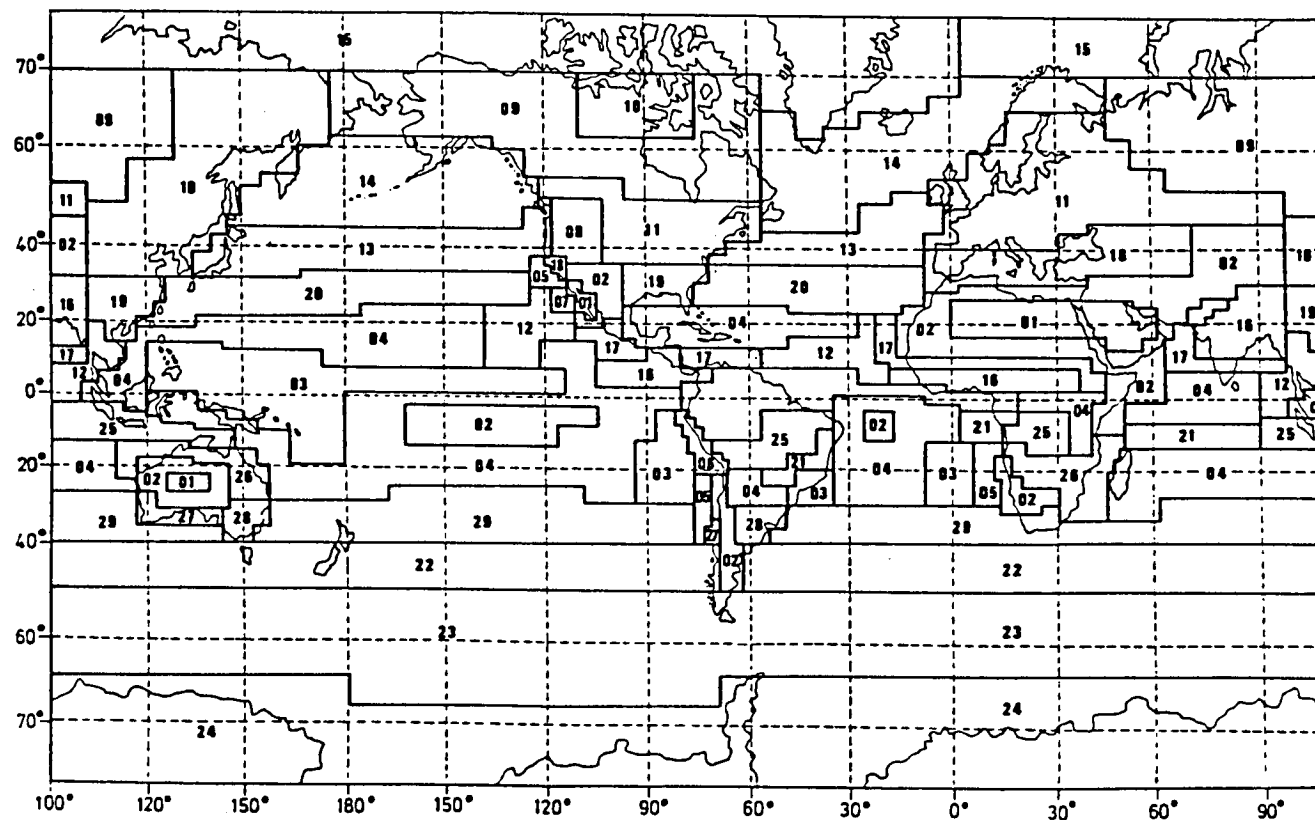


Figure 3 The positions of the 29 regions on the world map (after Sherr et al., 1968).

Table 1 Positions of the 29 cloud cover type regions for the  
10° latitude - 10° longitude model.

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	1
	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	2
	14	14	14	11	11	9	9	9	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	3
	11	11	11	11	11	11	9	9	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	4
	11	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	5
	13	13	13	13	13	13	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	6
	1	1	1	1	1	1	2	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	7
	2	2	2	2	2	2	2	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	8
	16	16	16	4	2	2	4	4	4	4	12	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	10	
	21	21	25	4	2	4	4	4	4	25	25	25	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	11	
	5	26	25	4	26	21	21	21	21	4	4	26	25	25	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	3	6	25	25	21	4	4	12
	3	2	26	26	4	4	4	4	4	4	4	2	1	2	26	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	5	4	4	4	13	
	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	14	
	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	15	
	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	16	
	23	24	24	23	24	24	23	24	24	23	24	24	24	23	24	24	23	24	24	23	24	23	24	23	24	23	24	23	24	23	24	23	24	24	24	17	
	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	18	
	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	K	

Table 2 General Description of Climatological Regions  
after Sherr, et al., 1968).

1	2	3	4	5	6	7	8	9
Region Number	General Description	Location	Seasonal Change in Cloud Amount	Mean Monthly Cloud Amount Jun-Aug (in Percent)	Mean Monthly Cloud Amount Dec-Mar (in Percent)	Predominant Cloud Type	Diurnal Variation in Cloud Amount	Hour of Maximum Cloud Amount (Local Time)
01	Essentially Clear	Major Desert Area	Small	< 20	< 20	--	Small	--
02	Little Cloudiness	Sub-Desert Areas	Small	< 40	< 40	--	Small	----
03	Tropical Cloudy	Near Equator	Small	> 60	> 60	Convective	Large	1400
04	Tropical Moderate Cloudiness	North or South of Region 03	Small	~ 50	~ 50	Convective	Large	1600
05	Desert Marine	Over Ocean - off West Coasts	Small	~ 50	~ 50	Stratiform	Large	0800
06	Desert Marine Cloudy Winter	Over Ocean - West of Peru	Extreme	> 70	< 30	Stratiform	Large	0600
07	Desert Marine Cloudy Summer	Over Ocean - West of Baja California	Extreme	> 70	< 30	Stratiform	Large	0800
08	Mid Latitude - Clear Summer	North America	Extreme	~ 40	~ 70	Synoptic Scale	Small	----
09	High Latitude - Cloudy Summer	North America, Asia	Moderate	~ 70	~ 50	Synoptic Scale	Small	----
10	High Latitude - Clear Winter	Asia, North America	Extreme	~ 70	< 30	Synoptic Scale	Small	----
11	Mid Latitude - Land	Northern Hemisphere	Moderate	~ 50	~ 70	Synoptic Scale	Small	----
12	Tropical - Cloudy Summer	North of Region 03	Moderate	> 60	~ 50	Convective	Large	1600
13	Mid Latitude - Ocean	Northern Hemisphere	Moderate	~ 60	> 70	Synoptic Scale	Small	----

Table 2 Continued.

1	2	3	4	5	6	7	8	9
14	High Latitude - Ocean	Northern Hemisphere	Moderate	>80	~70	Synoptic Scale	Small	----
15	Polar	Northern Hemisphere	Small	~60	~60	Synoptic Scale	Small	----
16	Tropical - Seasonal Change	North of Region 03	Extreme	>70	<40	Convective	Large	1600
17	Tropical - Clear Winter	Northern Hemisphere Near Region 16	Moderate	~50	<30	Convective	Large	1600
18	Mediterranean	Northern Hemisphere Europe, Western North America	Extreme	~30	--	Convective	Small	----
				--	~60	Synoptic Scale	Small	----
19	Sub Tropical	Northern Hemisphere ~30N	Moderate	<50	--	Convective	Large	1600
				--	~60	Synoptic Scale	Small	----
20	Sub Tropical - Ocean	Northern Hemisphere ~30N	Moderate	~50	--	Convective	Small	----
				--	>60	Synoptic Scale	Small	----
21	Tropical - Cloudy Summer	South of Region 03	Moderate	~50	>60	Convective	Large	1600
22	Mid Latitude Ocean	Southern Hemisphere	Moderate	>70	~60	Synoptic Scale	Small	----
23	High Latitude - Ocean	Southern Hemisphere	Moderate	~70	>80	Synoptic Scale	Small	----
24	Polar	Southern Hemisphere	Small	~60	~60	Synoptic Scale	Small	----
25	Tropical - Seasonal Change	South of Region 03	Extreme	<40	>70	Convective	Large	1600
26	Tropical - Clear Winter	South of Region 25; Africa, Australia	Moderate	<30	~50	Convective	Large	1600
27	Mediterranean	Southern Hemisphere Australia, Chile	Extreme	--	~30	Convective	Small	----
				~60	--	Synoptic Scale	Small	----
28	Sub Tropical Land	Southern Hemisphere ~30S	Moderate	--	<50	Convective	Large	1600
				~60	--	Synoptic Scale	Small	----
29	Sub Tropical - Ocean	Southern ~30S	Moderate	--	~50	Convective	Small	----
				>60	--	Synoptic Scale	Small	----



month and time of the day, on the  $10^0 \times 10^0$  grid of our model. Each table is identified with the name of the month and the local time.

A calculation of the global annual percent cloud cover from the above data gave a value of 60% which is much larger than values of 50-55% normally used (i.e. The global cloudiness for Model A of Hoyt (1976) was 53.2%).

A multiplying factor  $GLCLC/60$  has been incorporated into the model. By means of this factor the global cloud cover may be adjusted to any desired fraction equal to  $GLCLC$ . When  $GLCLC$  is specified at the beginning of a computer run, all values of percent cloud cover (PC) are adjusted by the multiplying factor with the result that the annual global fractional cloud cover is made equal to  $GLCLC$ .

## 2.5 Cloud Albedo

The paper of Sherr, et al., did not supply information on cloud albedo for each of the 29 cloud climatic regions. Therefore, cloud albedo was estimated by using the cloud albedo function of Larson and Backstrom (1977) along with a multiplying factor  $RA(NT)$  which attempts to adjust the Larson and Backstrom function to the specific type of clouds in the given cloud climatic region. This factor was selected for each climatic region by comparing the general description for each region with the data of Krondratyev (1973). The factors  $RA(NT)$  are listed in Table 3. Also shown in the table are the fractional amounts of the earth's area occupied by each cloud climatic type. Most cloud types each occupy less than 5% of the world area; however, cloud type 23 occupies 6.6% and cloud type 4 occupies 18.1% in this model.

The albedo of cloud type NT then is given albedo equal to

$$\left\{ 79.7(1-0.176 \cos(\theta)) \cdot RA(NT) \right\} \quad (7)$$

where  $\theta$  = the zenith angle of the sun

$RA(NT)$  = cloud albedo multiplying factor for cloud climatic area NT.

Table 3 Cloud albedo factors RA(NT). Fractional area of the earth for each cloud type is also shown.

<u>NT</u>	<u>RA(NT)</u>	<u>AREA (FRACTIONAL)</u>
1.	.625	.01535
2.	.425	.08921
3.	.6	.09011
4.	.6	.18161
5.	.6	.00651
6.	.6	.00235
7.	.6	.00221
8.	.6	.00171
9.	.85	.03511
10.	.85	.03618
11.	.85	.01861
12.	.85	.02316
13.	1.0	.03151
14.	1.0	.02215
15.	.92	.03425
16.	.85	.01842
17.	.85	.01403
18.	.78	.01875
19.	.78	.00836
20.	.85	.04312
21.	1.0	.02508
22.	.82	.04793
23.	.85	.06636
24.	1.0	.05062
25.	1.0	.02815
26.	1.0	.01360
27.	1.0	.00568
28.	.78	.00595
29.	.78	.06388

## 2.6 Resultant albedo of each $10^0 \times 10^0$ region

The resultant albedo of each  $10^0 \times 10^0$  region is a function of eight parameters.

It can be expressed as:

$$\begin{aligned}
 & C(I, J, K, \theta, LT, NT, N, GLCLC) \\
 & = \left\{ \begin{array}{l} \text{Surface} + \\ \text{Atmosphere} \end{array} \right\} (1 - PC(LT, NT, N) \frac{GLCLC}{60}) \\
 & \quad + \left\{ \text{Clouds} \right\} PC(LT, NT, N) \frac{GLCLC}{60}
 \end{aligned} \tag{8}$$

where:

I = season or month index (for surface albedo)

J = longitude index

K = latitude index

$\theta$  = solar zenith angle

LT = local time index

NT = cloud climatic region index

N = month index (for % cloud cover)

PC = percent cloud cover

$$\left\{ \begin{array}{l} \text{surface} \\ + \\ \text{atmosphere} \end{array} \right\} = \text{albedo of earth atmosphere system}, \tag{4}$$

$$\left\{ \text{clouds} \right\} = \text{albedo of clouds}, \tag{7}$$

### 3. Earth Albedo Calculations

#### 3.1 Equation for Earth's Albedo

The calculation of the albedo of the earth at a given time on a given day is based on the portion of the earth illuminated by the sun at that time. As an example, Figure 4 shows, in schematic form, the portion of the earth illuminated by the sun at the summer solstice as shown in Byer (1974). The sub-solar point is at  $23^{\circ}27'$  north. The meridian through the sub-solar point is at noon local sun time. Solar times at other meridians at  $45^{\circ}$  intervals of relative longitude are also shown.

The longitude of noon local sun time will vary as a function of Greenwich mean time. In this program, earth albedo calculations are made at 0:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, and 21:00 G.M.T. The corresponding longitudes of the sub-solar point are,  $0.0^{\circ}$ ,  $45.0^{\circ}$ ,  $90.0^{\circ}$ ,  $135.0^{\circ}$ ,  $180.0^{\circ}$ ,  $225.0^{\circ}$ ,  $270.0^{\circ}$  and  $315.0^{\circ}$  west, respectively.

The averaging (integration) of albedo over the sunlit hemisphere of the earth is carried out using the coordinate system illustrated in Figure 5. In Figure 5,  $\theta$  corresponds to the zenith angle at a given element of area on the sunlit portion of the earth's surface,  $\alpha$  is an azimuth angle around the sub-solar point. The limits for the integration are

$$\begin{aligned} 0 &\leq \theta \leq 90^{\circ} \\ 0 &\leq \alpha \leq 360^{\circ} \end{aligned}$$

The integral relation for the average albedo of the sunlit portion of the earth is:

$$A = \frac{1}{\pi} \int_0^{2\pi} \int_0^{\pi/2} R(\theta) \cos \theta \sin \theta \, d\theta \, d\alpha \quad (9)$$

where  $R(\theta)$  is the albedo (directional reflectance) of the element of area at zenith angle  $\theta$  and azimuth angle  $\phi$ . It is assumed that  $R(\theta)$  is independent of

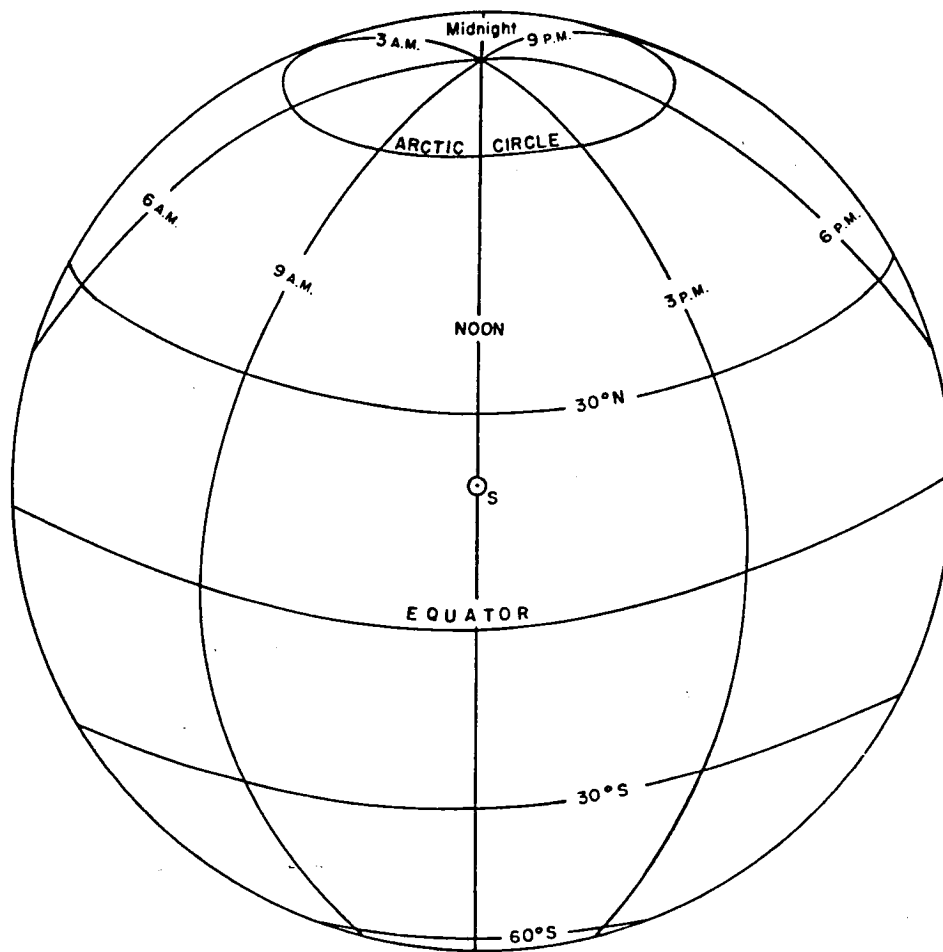


Figure 4 Exposure of the earth to the sun at the summer solstice, with subsolar point at S marking noon. Times on other meridians at  $45^\circ$  intervals of longitude are shown (after Byer, 1974).

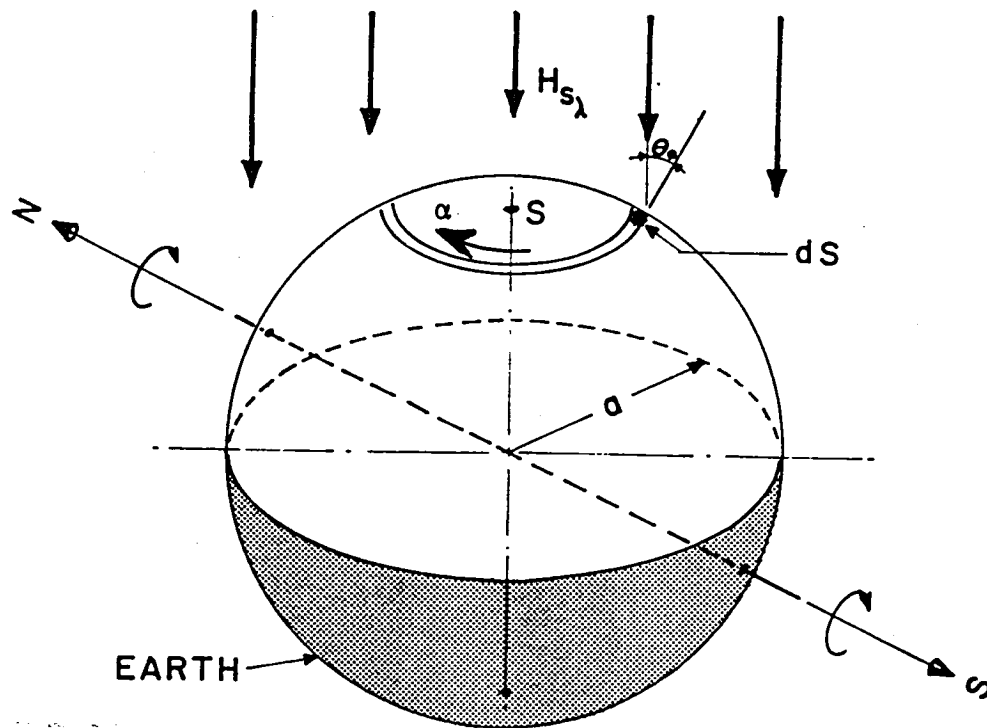


Figure 5 Coordinate system for integration of albedo over sunlit portion of earth.

$\phi$ . The computer program carries out the integration using a summation over  $5^\circ$  zenith angle and  $5^\circ$  azimuth angle intervals, thus:

$$A = \frac{1}{\pi} \sum_L \sum_M C(L,B) \sin \theta \cos \theta \Delta \theta \Delta \alpha \quad (10)$$

since  $\Delta \alpha = \frac{\pi}{2.18}$  and  $\Delta \phi = \frac{2\pi}{72}$

$$A = .002424 \sum_L \sum_M C(L,M) \sin \theta \cos \theta \quad (11)$$

In equations 10 and 11,  $C(L,M)$  is a function of  $L$  and  $M$ , which identify an area relative to the sub-solar point. Equation (8) indicates that  $C$ , the albedo of an area on the surface of the earth, depends on many parameters:  $I, J, K, \theta, LT, NT, N$ , and  $GLCLC$ . Many of these parameters, i.e.,  $J, K, \theta, LT$ , and  $NT$  are functions of  $L$  and  $M$ . The calculations which relate these parameters to  $L, M$  are described in the next section of this report.

### 3.2 Sequence of FORTRAN Computer Program Calculations

The sequence of calculations required for the determination of average earth albedo at a given time, by the FORTRAN computer program, starts (computer program statement number 14.4) with the input of indices for the month of the year ( $I$  for surface albedo and  $N$  for cloud cover) and of the global annual average percent cloud cover,  $GLCLC$ . The value of another index  $NI$ , which acts as a "switch" in the program is also specified. The computer program which carries out the calculations is listed completely in Appendix C without explanatory comments.

The sequence of significant instructions carried out by the computer program is as follows. (The computer program statement numbers are given in parenthesis for each set of instructions).

1. Calculate the sub-solar point longitude,  $\lambda_s$ , for each of the eight local times of the day (16).
2. Determine the sub-solar point latitude,  $\delta_s$ , for that month (19-30).
3. Loop through 18 values of  $\theta$  (31,32).
4. For each  $\theta$  calculate  $M_s$  and  $A_s$  (33,34)
5. Loop through 72 values of  $\alpha$  (36,37)
6. For each value of  $\theta$  and  $\alpha$ , determine the corresponding values of latitude  $\beta$ , hour angle of the sun,  $h_s$ , and longitude  $\lambda$  (38-47).
7. Determine the latitude and longitude indices, K and J corresponding to latitude  $\beta$  and longitude  $\lambda$  (48-49).
8. Determine the cloud climatological type index NT corresponding to latitude  $\beta$  and longitude  $\lambda$  (50).
9. Determine local solar time and local solar time index LT corresponding to the sun's hour angle,  $h_s$  (51-60).
10. Select value of surface albedo  $A(I,J,K)$ . Determine whether it corresponds to land, ocean or snow/ice area; branch accordingly (60.1-61.8).
11. Determine value of albedo, including surface, atmosphere and cloud cover contributions using appropriate relationship for land, ocean or snow/ice surface region (63-66, 67-70, or 71-74).
12. Determine the average value of albedo (averaged over the eight local times) for each  $10^0 \times 10^0$  area on the surface of the earth (74.2, 74.4, 86.3, 86.4, 86.41, 86.42).
13. Determine the average percent cloud cover of the sunlit portion of the earth at each of the eight times of the day (75,77).
14. Determine the albedo of the sunlit portion of the earth at each of the eight times of the day (76,78).



15. Write (output) the month index,  $I$ ; solar declination,  $\delta_s$ ; sub-solar point longitude, albedo and percent cloud cover of the sunlit portion of the earth for each of the eight times of the day (80).
16. Determine the average albedo for the day and the average percent cloud cover of the sunlit portion of the earth for the day and output these values (81-86).
17. Determine zonal average albedos for the day and output results (86.48-86.7).
18. Go back to the beginning of the program and input another set of values of  $I, N, NI, GLCLC$ .
19. The program is run through completely for each of the 12 months of the year.

The other FORTRAN program statements not described above are for data initialization, for input of data from files, for the use of switches controlling the output of data, or else they are non-executable statements for variable type and dimension or input and output format statements.

### 3.3 Results

#### 3.31 Daily Variation of Earth's Albedo

Tables 4 to 15 show results of the albedo calculations for each of the 12 months of the year, respectively, with a global yearly average cloud cover equal to 0.45. Each table shows the month index ( $I$ ), solar declination angle ( $DELTA_S$ ), sub-solar point longitude ( $SSLON$ ), albedo at that time ( $ALBEDO$ ) and percent cloud cover for the sunlit hemisphere of the earth ( $PC$ ). The average albedo for the day ( $ALB$ ) and the average sunlight percent cloud cover for the day ( $PC$ ) are shown below the main body of the table.

Recall that the correspondence between the time of day and the sub-solar

I= 1	DELTAS=-20.08	SSLON= 0.0	ALBEDC=	31.53	PC=0.50	
I= 1	DELTAS=-20.08	SSLON= 45.00	ALBEDC=	30.77	PC=0.50	
I= 1	DELTAS=-20.08	SSLON= 90.00	ALBEDC=	29.71	PC=0.49	
I= 1	DELTAS=-20.08	SSLON=135.00	ALBEDC=	28.81	PC=0.50	4.
I= 1	DELTAS=-20.08	SSLON=180.00	ALBEDC=	29.50	PC=0.49	
I= 1	DELTAS=-20.08	SSLON=225.00	ALBEDC=	31.07	PC=0.49	JAN.
I= 1	DELTAS=-20.08	SSLON=270.00	ALBEDC=	31.95	PC=0.49	
I= 1	DELTAS=-20.08	SSLON=315.00	ALBEDC=	31.49	PC=0.49	

ALB= 30.60 PC= 0.493

I= 2	DELTAS=-10.83	SSLON= 0.0	ALBEDC=	30.17	PC=0.47	
I= 2	DELTAS=-10.83	SSLON= 45.00	ALBEDC=	29.62	PC=0.48	
I= 2	DELTAS=-10.83	SSLON= 90.00	ALBEDC=	28.68	PC=0.48	
I= 2	DELTAS=-10.83	SSLON=135.00	ALBEDC=	27.63	PC=0.48	5.
I= 2	DELTAS=-10.83	SSLON=180.00	ALBEDC=	28.51	PC=0.47	
I= 2	DELTAS=-10.83	SSLON=225.00	ALBEDC=	29.99	PC=0.47	FEB.
I= 2	DELTAS=-10.83	SSLON=270.00	ALBEDC=	30.78	PC=0.47	
I= 2	DELTAS=-10.83	SSLON=315.00	ALBEDC=	30.13	PC=0.47	

ALB= 29.44 PC= 0.472

I= 3	DELTAS= -0.08	SSLON= 0.0	ALBEDC=	30.02	PC=0.47	
I= 3	DELTAS= -0.08	SSLON= 45.00	ALBEDC=	29.62	PC=0.47	
I= 3	DELTAS= -0.08	SSLON= 90.00	ALBEDC=	28.36	PC=0.47	
I= 3	DELTAS= -0.08	SSLON=135.00	ALBEDC=	27.49	PC=0.47	6.
I= 3	DELTAS= -0.08	SSLON=180.00	ALBEDC=	28.63	PC=0.47	
I= 3	DELTAS= -0.08	SSLON=225.00	ALBEDC=	30.12	PC=0.47	MAR.
I= 3	DELTAS= -0.08	SSLON=270.00	ALBEDC=	30.38	PC=0.47	
I= 3	DELTAS= -0.08	SSLON=315.00	ALBEDC=	29.85	PC=0.46	

ALB= 29.31 PC= 0.468

I= 4	DELTAS= 11.58	SSLON= 0.0	ALBEDC=	30.34	PC=0.46	
I= 4	DELTAS= 11.58	SSLON= 45.00	ALBEDC=	30.19	PC=0.46	
I= 4	DELTAS= 11.58	SSLON= 90.00	ALBEDC=	29.37	PC=0.46	7.
I= 4	DELTAS= 11.58	SSLON=135.00	ALBEDC=	28.70	PC=0.47	
I= 4	DELTAS= 11.58	SSLON=180.00	ALBEDC=	29.65	PC=0.46	APR.
I= 4	DELTAS= 11.58	SSLON=225.00	ALBEDC=	31.01	PC=0.47	
I= 4	DELTAS= 11.58	SSLON=270.00	ALBEDC=	31.04	PC=0.47	
I= 4	DELTAS= 11.58	SSLON=315.00	ALBEDC=	30.43	PC=0.46	

ALB= 30.09 PC= 0.463

Tables 4-7 Results of albedo calculations. Month index (I), solar declination (DELTAS), sub-solar point longitude (SSLON), albedo for that sub-solar point (ALBEDO), percent cloud cover for the sunlit hemisphere of the earth (PC), average albedo for the day (ALB), and average sunlit percent cloud cover for the day (PC).

I= 5	DELTAS= 20.03	SSLON= 0.0	ALBEDO= 30.54	PC=0.46
I= 5	DELTAS= 20.03	SSLON= 45.00	ALBEDC= 30.88	PC=0.47
I= 5	DELTAS= 20.03	SSLON= 90.00	ALBEDO= 30.56	PC=0.48
I= 5	DELTAS= 20.03	SSLON=135.00	ALBEDC= 30.41	PC=0.50
I= 5	DELTAS= 20.03	SSLON=180.00	ALBEDC= 30.99	PC=0.48
I= 5	DELTAS= 20.03	SSLON=225.00	ALBEDC= 31.60	PC=0.48
I= 5	DELTAS= 20.03	SSLON=270.00	ALBEDC= 31.35	PC=0.47
I= 5	DELTAS= 20.03	SSLON=315.00	ALBEDO= 30.70	PC=0.47

8.

MAY

ALB= 30.88 PC= 0.476

I= 6	DELTAS= 23.45	SSLON= 0.0	ALBEDO= 30.37	PC=0.47
I= 6	DELTAS= 23.45	SSLON= 45.00	ALBEDO= 31.18	PC=0.47
I= 6	DELTAS= 23.45	SSLON= 90.00	ALBEDC= 31.43	PC=0.50
I= 6	DELTAS= 23.45	SSLON=135.00	ALBEDO= 31.35	PC=0.53
I= 6	DELTAS= 23.45	SSLON=180.00	ALBEDC= 31.69	PC=0.51
I= 6	DELTAS= 23.45	SSLON=225.00	ALBEDO= 32.20	PC=0.50
I= 6	DELTAS= 23.45	SSLON=270.00	ALBEDO= 31.11	PC=0.48
I= 6	DELTAS= 23.45	SSLON=315.00	ALBEDO= 30.25	PC=0.47

9.

JUNE

ALB= 31.20 PC= 0.490

I= 7	DELTAS= 20.63	SSLON= 0.0	ALBEDO= 28.93	PC=0.45
I= 7	DELTAS= 20.63	SSLON= 45.00	ALBEDO= 30.42	PC=0.46
I= 7	DELTAS= 20.63	SSLON= 90.00	ALBEDC= 30.70	PC=0.50
I= 7	DELTAS= 20.63	SSLON=135.00	ALBEDO= 30.42	PC=0.52
I= 7	DELTAS= 20.63	SSLON=180.00	ALBEDO= 30.77	PC=0.50
I= 7	DELTAS= 20.63	SSLON=225.00	ALBEDC= 31.18	PC=0.49
I= 7	DELTAS= 20.63	SSLON=270.00	ALBEDO= 29.80	PC=0.47
I= 7	DELTAS= 20.63	SSLON=315.00	ALBEDO= 28.79	PC=0.45

10.

JULY

ALB= 30.13 PC= 0.481

I= 8	DELTAS= 12.38	SSLON= 0.0	ALBEDC= 28.63	PC=0.45
I= 8	DELTAS= 12.38	SSLON= 45.00	ALBEDO= 29.65	PC=0.47
I= 8	DELTAS= 12.38	SSLON= 90.00	ALBEDO= 29.49	PC=0.49
I= 8	DELTAS= 12.38	SSLON=135.00	ALBEDO= 29.12	PC=0.51
I= 8	DELTAS= 12.38	SSLON=180.00	ALBEDO= 29.37	PC=0.50
I= 8	DELTAS= 12.38	SSLON=225.00	ALBEDC= 29.73	PC=0.49
I= 8	DELTAS= 12.38	SSLON=270.00	ALBEDC= 28.78	PC=0.46
I= 8	DELTAS= 12.38	SSLON=315.00	ALBEDC= 28.14	PC=0.45

11.

AUG.

ALB= 29.11 PC= 0.478

Tables 8-11 Results of albedo calculations. Month index (I), solar declination (DELTAS), sub-solar point longitude (SSLON), albedo for that sub-solar point (ALBEDO), percent cloud cover for the sunlit hemisphere of the earth (PC), average albedo for the day (ALB), and average sunlit percent cloud cover for the day (PC).

I= 9	DELTAS=	1.02	SSLON=	0.0	ALBEDO=	28.66	PC=0.46
I= 9	DELTAS=	1.02	SSLON=	45.00	ALBEDO=	29.83	PC=0.47
I= 9	DELTAS=	1.02	SSLON=	90.00	ALBEDO=	29.72	PC=0.50
I= 9	DELTAS=	1.02	SSLON=	135.00	ALBEDO=	29.24	PC=0.51
I= 9	DELTAS=	1.02	SSLON=	180.00	ALBEDO=	29.45	PC=0.50
I= 9	DELTAS=	1.02	SSLON=	225.00	ALBEDC=	29.91	PC=0.49
I= 9	DELTAS=	1.02	SSLON=	270.00	ALBEDC=	29.18	PC=0.46
I= 9	DELTAS=	1.02	SSLON=	315.00	ALBEDC=	28.32	PC=0.45

12  
SEPT.

ALB= 29.29 PC= 0.480

I=10	DELTAS=-11.42	SSLON=	0.0	ALBEDO=	29.92	PC=0.46
I=10	DELTAS=-11.42	SSLON=	45.00	ALBEDO=	30.59	PC=0.47
I=10	DELTAS=-11.42	SSLON=	90.00	ALBEDO=	29.59	PC=0.48
I=10	DELTAS=-11.42	SSLON=	135.00	ALBEDC=	28.70	PC=0.49
I=10	DELTAS=-11.42	SSLON=	180.00	ALBEDO=	29.21	PC=0.48
I=10	DELTAS=-11.42	SSLON=	225.00	ALBEDC=	30.07	PC=0.47
I=10	DELTAS=-11.42	SSLON=	270.00	ALBEDO=	30.33	PC=0.46
I=10	DELTAS=-11.42	SSLON=	315.00	ALBEDC=	29.71	PC=0.45

13  
OCT.

ALB= 29.77 PC= 0.469

I=11	DELTAS=-19.75	SSLON=	0.0	ALBEDO=	32.39	PC=0.50
I=11	DELTAS=-19.75	SSLON=	45.00	ALBEDO=	32.10	PC=0.51
I=11	DELTAS=-19.75	SSLON=	90.00	ALBEDC=	30.73	PC=0.51
I=11	DELTAS=-19.75	SSLON=	135.00	ALBEDC=	29.81	PC=0.52
I=11	DELTAS=-19.75	SSLON=	180.00	ALBEDO=	30.56	PC=0.51
I=11	DELTAS=-19.75	SSLON=	225.00	ALBEDC=	31.89	PC=0.50
I=11	DELTAS=-19.75	SSLON=	270.00	ALBEDC=	32.64	PC=0.50
I=11	DELTAS=-19.75	SSLON=	315.00	ALBEDO=	32.24	PC=0.49

14  
NOV.

ALB= 31.55 PC= 0.506

I=12	DELTAS=-23.43	SSLON=	0.0	ALBEDO=	33.24	PC=0.52
I=12	DELTAS=-23.43	SSLON=	45.00	ALBEDO=	32.66	PC=0.52
I=12	DELTAS=-23.43	SSLON=	90.00	ALBEDO=	31.47	PC=0.53
I=12	DELTAS=-23.43	SSLON=	135.00	ALBEDO=	30.65	PC=0.53
I=12	DELTAS=-23.43	SSLON=	180.00	ALBEDC=	31.35	PC=0.53
I=12	DELTAS=-23.43	SSLON=	225.00	ALBEDO=	32.76	PC=0.52
I=12	DELTAS=-23.43	SSLON=	270.00	ALBEDC=	33.42	PC=0.52
I=12	DELTAS=-23.43	SSLON=	315.00	ALBEDO=	33.16	PC=0.51

15  
DEC.

ALB= 32.34 PC= 0.523

Tables 12- 15 Results of albedo calculations. Month index (I), solar declination (DELTAS), sub-solar point longitude (SSLON), albedo for that sub-solar point (ALBEDO), percent cloud cover for the sunlit hemisphere of the earth (PC), average albedo for the day (ALB), and average sunlit percent cloud cover for the day (PC).

point longitude is as follows:

<u>GMT(HOURS)</u>	<u>SSLON(DEG)</u>
00:00	0.0
03:00	45.0
06:00	90.0
09:00	135.0
12:00	180.0
15:00	225.0
18:00	270.0
21:00	315.0

These tables show that during the months of October through April the daily minimum value of earth's albedo is at 09:00 GMT, when the sub-solar longitude is at  $135^{\circ}$  in the center of the Pacific Ocean area. During most of these months the solar declination is negative (the sub-solar point is south of the equator). During the same period of time the daily maximum value of earth's albedo is at 18:00 GMT, at longitude  $270^{\circ}$ , when the sub-solar point is over the Indian Ocean.

From May to September, when the solar declination is positive, the minimum daily albedo is between 21:00 GMT and 24:00 GMT, when the sub-solar longitude is between  $315^{\circ}$ W and the Greenwich meridian. The maximum daily albedo is at 15:00 GMT, when the sub-solar point is at  $225^{\circ}$  longitude, in the western Pacific Ocean. In January and February, the diurnal variation is  $\pm 5\%$  of the daily average value. In May, it is only  $\pm 1.75\%$  of the daily average value.

Monthly zonal averages of earth's albedo are shown in Table 16. Monthly global averages of albedo and percent cloud cover in sunlight are shown in the table below the zonal averages. The monthly global albedo averages have a maximum in June and a larger maximum in December. Minima of monthly global

albedo values occur in February-March and August-September. The variations in monthly average albedo are in general agreement with the variations in the monthly average values of percent cloud cover in sunlight. The albedo is a maximum when percent cloud cover in daylight is a maximum.

The monthly zonal average values of albedo are compared with the satellite measured zonal average values of Ellis and Vonder Haar (1976) in Table 17. The table shows the value of the difference (Ellis and Vonder Haar's value minus the model value). Considerable refinement of the model is needed to obtain agreement with Ellis and Vonder Haar.

Table 16 Monthly zonal averages of earth's albedo. Monthly and yearly global averages of earth's albedo (ALB) and of percent cloud cover in sunlight (SPC) are also shown.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	K	
0.0	0.0	52.2	55.8	61.0	59.4	56.6	55.1	55.6	0.0	0.0	0.0	1	
0.0	51.5	53.0	52.5	56.8	54.5	51.9	49.6	51.9	51.8	0.0	0.0	2	
50.0	50.9	52.4	52.0	49.1	42.6	40.2	40.2	43.4	46.4	49.1	50.5	3	
49.3	46.0	45.5	43.6	42.5	40.7	40.1	39.9	40.8	41.9	44.7	47.8	4	
43.4	40.2	38.4	36.9	36.2	34.4	32.7	33.0	32.6	34.9	39.3	41.9	5	
34.5	33.8	33.6	33.0	32.6	31.4	27.6	26.6	25.5	29.7	33.5	34.9	6	ZONAL
25.5	25.3	25.7	25.4	25.4	26.1	25.7	24.5	24.2	24.3	26.2	26.8	7	ALBEDO
22.3	21.0	20.7	22.0	24.6	26.5	26.9	26.5	27.2	26.4	25.3	24.5	8	
22.3	21.8	21.8	22.4	24.6	27.8	28.5	28.4	28.2	26.1	25.9	24.8	9	
24.5	23.9	23.8	23.7	20.8	21.0	20.6	20.1	21.1	22.2	24.1	25.2	10	
28.1	28.2	28.4	28.3	24.9	25.7	25.4	24.0	23.9	24.0	26.5	28.2	11	28
22.3	22.3	22.4	22.8	22.4	24.5	25.0	24.1	23.5	21.0	21.7	22.8	12	
28.7	25.4	24.2	28.7	32.8	33.6	32.0	32.3	32.6	31.7	32.2	32.8	13	
32.9	32.5	34.8	38.5	41.5	41.6	41.4	39.4	37.7	36.9	35.9	34.6	14	
43.3	43.7	44.7	46.5	48.9	50.6	50.1	48.6	46.5	44.7	43.7	43.9	15	
49.2	50.6	52.4	51.9	50.4	47.4	47.6	50.5	51.7	50.6	52.7	51.4	16	
60.4	61.2	62.2	59.9	0.0	0.0	0.0	53.6	58.3	59.4	61.0	61.9	17	
64.1	64.2	62.3	0.0	0.0	0.0	0.0	0.0	55.2	60.2	64.5	65.1	18	
30.6	29.4	29.3	30.1	30.9	31.2	30.1	29.1	29.3	29.8	31.5	32.3	30.3	ALBEDO
.493	.472	.468	.463	.477	.490	.481	.478	.480	.469	.506	.523	.487	SPC

Table 17 Difference between monthly zonal average albedo of Ellis and Vonder Haar and of this model (AEVH -AE).

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	K
0.0	0.0	0.4	7.2	1.0	-0.0	-0.5	0.4	0.4	0.0	0.0	0.0	1
0.0	-0.2	-0.4	7.7	3.7	0.3	-1.5	-1.8	-2.3	-0.3	0.0	0.0	2
4.6	1.4	-2.9	3.4	1.8	0.9	-1.6	-0.3	-6.4	2.5	5.2	0.9	3
6.6	-0.2	0.4	-2.0	-0.5	-0.5	-2.7	-2.8	-7.7	0.1	1.1	3.6	4
4.2	3.1	2.3	-1.6	-1.2	1.1	0.5	-1.7	-1.4	-2.2	-2.3	0.9	5
3.4	3.3	0.8	-1.4	-2.4	-2.2	0.2	-0.9	3.5	-0.6	-1.0	0.7	6
3.0	4.1	1.7	0.1	1.2	1.2	0.9	1.6	2.2	1.4	2.5	3.3	7
0.8	3.4	2.3	-0.1	-0.8	-1.3	-0.5	1.0	-1.0	-1.8	0.7	1.4	8
1.9	2.4	1.8	2.7	1.6	-0.8	-2.4	-2.0	-2.4	-1.3	-0.1	1.1	9
0.2	0.8	0.2	0.7	2.4	1.8	2.3	3.2	2.6	1.7	1.2	0.4	10
-3.5	-4.2	-4.9	-4.4	-1.6	-3.3	-3.2	-0.9	-0.8	-1.0	-1.7	-3.8	11
1.6	2.4	2.5	2.5	5.1	2.2	-0.3	0.6	1.9	3.6	3.5	1.8	12
-1.5	3.4	4.8	3.3	1.7	0.9	-1.4	-1.3	-3.0	-2.5	-3.6	-4.4	13
1.0	2.6	0.3	1.0	1.1	0.1	-0.5	-2.8	-2.7	-2.0	-1.5	-0.1	14
-3.6	-1.8	-3.3	0.5	-0.3	3.4	-0.6	0.4	-5.6	-1.0	-1.6	-2.9	15
-2.1	0.2	-1.8	2.4	11.6	2.6	2.4	-0.5	-1.2	7.1	-0.2	-1.0	16
-2.4	-1.5	-1.7	2.1	0.0	0.0	0.0	-3.6	1.7	5.8	0.4	-2.7	17
-4.6	-1.0	3.7	0.0	0.0	0.0	0.0	0.0	8.8	7.8	-4.0	-4.5	18

AEVH-AE



#### 4. Earth Albedo Measurements from Satellites

##### 4.1 Computer Program for Satellite Orbits

A computer program has been written for use in studying the effects of selective sampling of earth's albedo from satellites. Since earth's albedo varies yearly, seasonally, monthly and, indeed, daily and diurnally, the characteristics of the satellite orbit and the selective sampling thus imposed on the measurements could conceivably effect the results and our understanding of these variations.

A FORTRAN satellite orbit program called "Orbits," which has been written for studying the sampling problem is listed in Appendix D.

The sequence of calculations carried out by this program starts when the computer requests the input of satellite altitude, inclination angle and longitude of northbound equator crossing at the beginning of orbit 1 of the calculations (instruction 4). An index (switch) to determine the form of the output data is also requested. When these data are supplied, the calculations proceed as follows:

1. The orbital period  $P$  and rate of rotation of the earth relative to the satellite orbital plane,  $A = d\lambda/dt$  are calculated and printed out (statements 7-10).
2. Calculations are then made, once each minute, of satellite latitude and longitude (11-23).
3. Next, for each minute, the hour angle of the sun and the local sun time at the sub-satellite point are calculated (24-36).
4. As the satellite proceeds in orbit, the number of samples for each latitude-longitude area on the earth is accumulated as a function of local sun time and the results printed out as follows (45-49.6):
  - a) 24 tables, one for each hour of local sun time, showing the

- b) One table, showing latitude sampling as a function of local sun time, for all of the samples in the period of interest.

#### 4.2 Application of the Computer Program for Satellite Orbits to the Study of the Sampling Problem.

As an initial test of the program, the sampling characteristics of the Earth Radiation Budget System of satellites was calculated. Three satellites were included in the system with orbital characteristics as follows:

<u>Altitude</u>	<u>Inclination</u>	<u>Northbound Equator Crossing Time</u>	<u>Note</u>
833 km	98.74°	08:00	Sun-synchronous
833 km	98.74°	15:00	Sun-synchronous
600 km	50.00	00:00	Period = 96.654 min.

The results of these calculations for 30 days of sampling at the rate of 1 sample per minute are shown in tables 18 and 19. In these tables the number of samples in a one hour period are shown at the time corresponding to the beginning of that period. Table 18 shows the zonal sampling for the two sun-synchronous satellites for a period of 30 days. Comparison with Figure 6a indicates that this sampling study yields results comparable to those shown in Woerner and Cooper (1977). Note that Woerner and Cooper have results for northbound equator crossing times of 03:00 and 08:00 instead of 08:00 and 15:00, however.

Table 19 shows the 30 day zonal sampling for all three satellites. The data of Woerner and Cooper for three satellites are shown in Figure 6B. Again note that the sun-synchronous satellites for this figure have northbound equator crossing times of 03:00 and 08:00.

Latitude-longitude sampling for the three satellite system is shown in

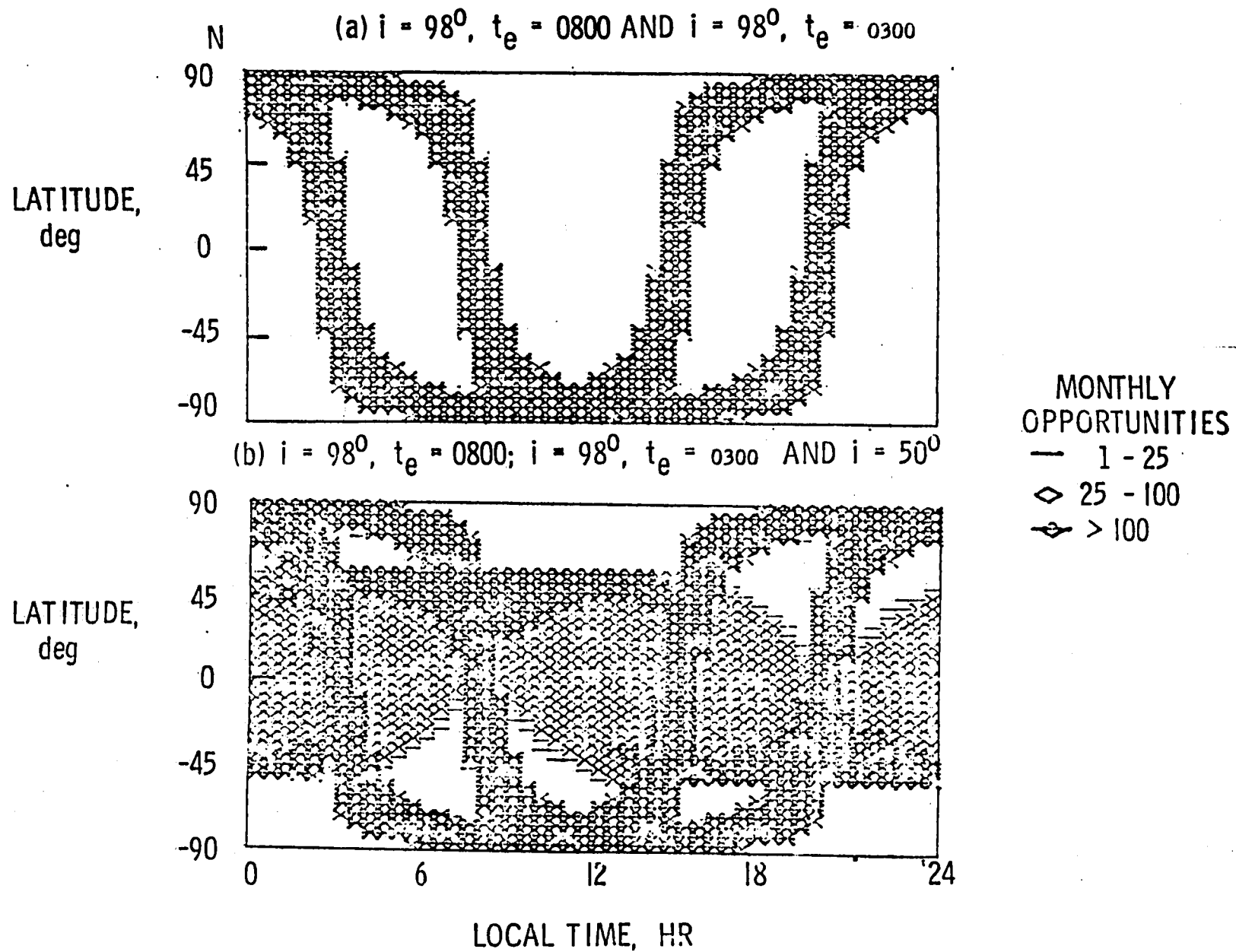


Figure 6 Temporal-Latitude Zonal Coverage for Multiple Satellites (after Woerner and Cooper, 1977).

Table 18 Temporal-Zonal sampling for two sun synchronous satellites for a period of 30 days.

0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	K
280	281	297	0	0	1	312	280	281	297	0	0	0	0	0	0	0	0	0	0	0	0	1	304	1
0	0	27	8651	468	805	7	0	0	27	440	746	374	0	0	0	0	0	0	0	425	722	431	7	2
0	0	191273	0	1290	0	0	0	0	0	0	0	1290	0	0	0	0	0	0	191273	0	0	0	0	3
0	01214	31	0	1691078	0	0	0	0	0	0	0	1691078	0	0	0	0	0	01214	31	0	0	0	0	4
0	01231	0	0	01231	0	0	0	0	0	0	0	01231	0	0	0	0	0	01231	0	0	0	0	0	5
0	01222	0	0	01223	0	0	0	0	0	0	0	01223	0	0	0	0	0	01222	0	0	0	0	0	6
0	01221	0	0	01220	0	0	0	0	0	0	0	01220	0	0	0	0	0	01221	0	0	0	0	0	7
0	01213	0	0	01216	0	0	0	0	0	0	0	01216	0	0	0	0	0	01213	0	0	0	0	0	8
0	295	919	0	0	01214	0	0	0	0	0	0	01213	0	0	0	0	0	295	919	0	0	0	0	9
01213	0	0	0	0	295	920	0	0	0	0	0	296	920	0	0	0	01213	0	0	0	0	0	0	10
01214	0	0	0	0	0	01214	0	0	0	0	0	0	01214	0	0	0	01214	0	0	0	0	0	0	11
01215	0	0	0	0	0	01215	0	0	0	0	0	0	01215	0	0	0	01215	0	0	0	0	0	0	12
01220	0	0	0	0	0	01220	0	0	0	0	0	0	01220	0	0	0	01220	0	0	0	0	0	0	13
01229	0	0	0	0	0	01227	0	0	0	0	0	0	01227	0	0	0	01229	0	0	0	0	0	0	14
1681075	0	0	0	0	0	01213	32	0	0	0	0	0	01213	32	0	1681075	0	0	0	0	0	0	0	15
1290	0	0	0	0	0	0	181271	0	0	0	0	0	181271	0	1290	0	0	0	0	0	0	0	20	16
371	0	0	0	0	0	0	0	421	721	430	7	0	0	25	8591465	801	7	0	0	25	438	724	17	
0	0	0	0	0	0	0	0	0	0	0	315	277	281	299	0	0	0	315	277	281	299	0	0	18

Table 19 Temporal-Zonal sampling for three satellite system for a period of 30 days.

0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	K
280	281	297	0	0	1	312	280	281	257	0	0	0	0	0	0	0	0	0	0	0	0	1	304	1
0	0	27	865	1468	805	7	0	0	27	440	746	374	0	0	0	0	0	0	0	425	722	431	7	2
0	0	191	273	0	1290	0	0	0	0	0	0	1290	0	0	0	0	0	0	191	273	0	0	0	3
0	0	1214	31	0	1691	080	1	2	1	2	1	1711	079	2	1	2	0	0	1214	31	0	0	0	4
0	0	1241	112	229	3351	663	548	664	656	697	696	6941	933	623	504	400	295	1921	297	0	0	0	0	5
0	161	361	171	174	1691	398	170	184	301	345	345	3431	468	171	175	169	174	1731	395	94	0	0	0	6
2	1191	373	151	148	1541	374	153	147	156	280	303	2331	373	151	148	154	151	1531	367	150	67	0	0	7
67	1451	350	137	142	1461	359	136	139	147	181	253	1411	362	146	138	136	143	1461	357	137	135	23	0	8
132	4371	063	135	138	1391	360	139	137	135	143	123	1431	356	137	136	140	144	4341	057	135	140	97	16	9
1351	349	139	142	138	135	4311	062	140	139	91	16	135	4281	058	140	143	1351	349	136	143	140	136	128	10
1471	353	138	146	147	143	1381	354	147	140	16	0	68	1391	361	146	142	1381	357	144	149	138	171	268	11
2291	362	153	152	151	146	1501	367	153	61	0	0	2	1171	364	152	152	1521	360	152	152	160	277	300	12
3411	468	170	173	174	174	1711	396	90	0	0	0	0	171	363	173	172	1731	396	170	183	303	345	358	13
7011	924	623	503	394	292	1891	293	0	0	0	0	0	0	1236	115	229	3341	666	546	667	697	696	679	14
1701	076	2	2	1	0	0121	3	32	0	0	0	0	0	1213	32	0	1681	077	1	2	2	1	1	15
1290	0	0	0	0	0	0	181	271	0	0	0	0	0	181	271	01290	0	0	0	0	0	0	20	16
371	0	0	0	0	0	0	0	421	721	430	7	0	0	25	8591	465	801	7	0	0	25	438	724	17
0	0	0	0	0	0	0	0	0	0	0	315	277	281	299	0	0	0	315	277	281	299	0	0	18

Tables D-1 to D-24. Each table shows latitude-longitude sampling for a given hour of the day. Note that even for the three satellite system, the sampling as a function of time is in general inadequate to determine diurnal variations in any latitude-longitude region of the earth.

#### 4.3 Further Study of the Effect of Sampling on Earth Albedo Determination from Satellites

The program for satellite orbits has been combined with the time variable model of earth's albedo, for further study of the satellite sampling problem in the determination of earth's albedo. Preliminary results have been obtained, but have not been studied carefully and, therefore, are not reported here.

## 5. Conclusion and Suggestions for Further Work

The albedo model described in this report is an initial attempt to describe the time varying nature of earth's albedo. The model is assembled in modular form. Each module can be modified independently of the others as described in the introduction.

Five conclusions can be drawn from this initial model:

1. The diurnal variation of earth's albedo is greatest ( $\pm 5\%$  of its daily average value) in January and February, when the sub-solar point is at  $20.08^\circ$  to  $10.83^\circ$  latitude in the southern hemisphere. At this time, the daily minimum value of earth's albedo is at 09:00 G.M.T., when the sub-solar longitude is at  $135^\circ$  in the center of the Pacific Ocean. The daily maximum value is at 18:00 G.M.T. when the sub-solar longitude is at longitude  $270^\circ$  in the Indian Ocean.

2. The diurnal variation of earth's albedo is smallest ( $\pm 1.75\%$  of its daily average value) in May, when the sub-solar point is at latitude  $20.03^\circ$  in the northern hemisphere. At this time, the daily minimum value of earth's albedo is between 21:00 and 24:00 G.M.T. when the sub-solar longitude is between  $315^\circ$ W and the Greenwich meridian. The daily maximum value is then at 15:00 G.M.T. when the sub-solar longitude is at  $225^\circ$  longitude in the western Pacific Ocean.

3. Maximum monthly global average values of albedo occur in June (31.2%) and December (32.3%) and minimum monthly values occur in February (29.4%) March (29.3%) and August (29.1%) and September (29.3%).

4. The global annual average cloud cover of only 45% produces a global annual average albedo of 30.3% which is approximately the value obtained from recent satellite measurements.

5. The annual percent cloud cover of the sunlit portion of the earth

(48%) is larger than the annual global cloud cover (45%) including both daylight and darkness.

Additional refinements of the model have been mentioned in the introduction. Each module of the model can be improved with a net improvement of the model.

The application of the model to the study of the effect of selective sampling from the three satellite ERBS system should be completed.

Finally, a procedure will be developed for the application of satellite data to improve the validity of the time variable earth albedo model.



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Appendix A

## Tables of Surface Albedo Values















Appendix B

## Tables of Percent Cloud Cover





[illegible]

**B-5 Percent cloud cover for 13:00 local time for January**

[illegible]

**B-6 Percent cloud cover for 16:00 local time for January**

	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
2	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
3	83	83	63	63	34	34	34	34	34	34	34	34	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
4	63	63	63	63	63	63	34	34	34	34	34	34	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
5	63	63	63	53	53	53	46	46	46	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
6	53	53	53	53	53	46	46	46	46	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
7	30	30	30	30	30	30	46	31	31	31	61	61	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67
8	46	46	46	46	46	46	32	32	31	31	68	47	66	66	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
9	31	31	31	47	46	46	47	47	47	47	68	47	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
10	82	82	88	47	46	47	47	47	47	47	88	47	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
11	44	32	88	47	82	82	82	82	82	47	47	82	88	88	47	47	66	66	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
12	66	46	82	82	47	47	47	47	47	47	47	46	30	46	82	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
13	72	72	72	72	72	72	72	72	72	72	72	23	23	53	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
14	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
15	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
16	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75	91	75	75
17	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
18	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75

B-7 Percent cloud cover for 19:00 local time for January

	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	
2	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	
3	81	81	58	53	39	39	39	39	39	39	39	21	21	21	21	21	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
4	53	58	58	58	58	58	39	39	39	39	39	21	21	21	21	21	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
5	58	58	58	50	50	50	50	40	40	40	40	21	21	21	21	21	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
6	50	50	50	50	50	40	40	40	40	40	40	21	21	21	21	21	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
7	22	22	22	22	22	22	40	24	24	24	57	57	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	
8	40	40	40	40	40	40	20	20	24	24	80	39	58	58	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
9	24	24	24	39	40	39	39	39	39	39	80	39	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	
10	96	96	73	39	40	39	39	39	39	39	73	73	73	39	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	
11	43	77	73	39	77	96	96	96	96	96	39	39	77	73	39	39	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	
12	58	40	77	77	39	39	39	39	39	39	39	40	22	40	77	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
13	74	74	74	74	74	74	74	74	74	74	74	74	27	27	35	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	
14	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	
15	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	
16	94	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	
17	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	
18	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	

B-8 Percent cloud cover for 22:00 local time for January

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33		
	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33		
	80	80	57	57	46	46	46	46	46	46	46	46	46	28	28	28	28	28	46	46	46	46	46	46	46	28	28	29	46	46	80	33	33	80	80	80	
	57	57	57	57	57	57	46	46	46	46	46	46	46	28	28	28	28	80	80	80	80	80	80	80	80	80	46	46	46	46	46	46	80	80	80	80	57
	57	57	57	47	47	47	47	33	33	33	28	28	28	28	28	77	77	77	77	77	77	77	77	77	77	77	77	54	57	57	57	57	57	77	77	77	57
	47	47	47	47	47	33	33	33	33	33	23	23	23	23	23	77	77	77	77	77	77	77	77	77	77	77	77	64	33	33	54	54	77	77	77	47	
	28	28	28	28	28	28	33	16	16	16	54	54	54	77	77	77	77	77	77	77	77	40	40	40	40	30	30	53	33	40	40	40	40	40	40	77	33
	33	33	33	33	33	33	30	30	16	16	10	40	44	44	40	40	40	40	40	40	40	40	40	40	40	30	30	40	30	30	16	30	30	30	30	33	
	16	16	16	40	33	33	40	40	40	40	40	40	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	40	16	16	40	44	44	44	44	16	
	91	91	64	40	33	40	40	40	40	64	64	64	40	44	44	44	44	44	40	33	33	33	33	33	33	40	40	40	44	44	64	64	40	33	40	40	
	47	71	64	40	81	91	91	91	91	40	40	81	64	64	40	40	44	44	40	40	40	40	40	40	40	40	40	40	40	40	44	84	64	64	91	40	40
	44	33	81	81	40	40	40	40	40	40	40	33	28	33	81	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	44	44	47	40	40	40	
	64	64	64	64	64	64	64	64	64	64	64	45	45	26	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	
	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	
	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	
	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	
	91	12	82	91	12	82	91	82	82	91	82	82	91	82	82	91	82	82	91	82	91	82	91	82	91	82	91	82	91	82	91	82	91	82	91	82	
	92	12	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	
	32	32	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	

B-9 Percent cloud cover for 01:00 local time for February

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	
	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	
	81	81	57	57	48	48	48	48	48	48	48	48	48	27	27	27	27	27	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	
	57	57	57	57	57	57	48	48	48	48	48	48	48	27	27	27	27	81	91	81	81	81	81	81	81	81	48	48	48	48	48	48	48	48	48	
	57	57	57	50	50	50	50	35	35	35	27	27	27	27	77	77	77	77	77	77	77	77	77	77	77	77	77	58	57	57	57	57	57	77	77	
	50	50	50	50	35	35	35	35	35	35	27	27	27	77	77	77	77	75	75	75	75	75	75	75	75	75	75	65	35	35	55	55	75	75	75	50
	28	28	28	28	28	28	35	18	18	18	55	55	75	75	75	75	75	40	40	40	40	42	42	51	35	40	40	40	40	40	40	40	40	40	75	35
	35	35	35	35	35	35	43	43	18	18	42	40	42	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	
	18	18	13	40	35	35	40	40	40	40	42	40	40	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	18	
	70	70	65	40	35	40	40	40	40	40	65	65	65	40	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	
	45	45	65	40	45	70	70	70	70	70	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	
	43	35	45	45	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	
	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	
	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	
	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	
	91	10	80	91	80	80	91	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	
	80	10	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	
	80	10	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	

B-10 Percent cloud cover for 04:00 local time for February

[illegible]

**B-11 Percent cloud cover for 07:00 local time for February**

[illegible]

**B-12 Percent cloud cover for 10:00 local time for February**







[illegible]

**B-17 Percent cloud cover for 01:00 local time for March**

[illegible]

**B-18 Percent cloud cover for 04:00 local time for March**

[illegible]

**B-19 Percent cloud cover for 07:00 local time for March**

[illegible]

**B-20 Percent cloud cover for 10:00 local time for March**

[illegible]

**B-21 Percent cloud cover for 13:00 local time for March**

[illegible]

**B-22 Percent cloud cover for 16:00 local time for March**



[illegible]

**B-25 Percent cloud cover for 01:00 local time for April**

[illegible]

**B-26 Percent cloud cover for 04:00 local time for April**

61

[illegible]

**B-28 Percent cloud cover for 10:00 local time for April**







[illegible]

**B-33 Percent cloud cover for 01:00 local time for May**

[illegible]

**B-34 Percent cloud cover for 04:00 local time for May**





67

**B-40 Percent cloud cover for 22:00 local time May**









[illegible]

**B-47 Percent cloud cover for 19:00 local time for June**

[illegible]

B-48 Percent cloud cover for 22:00 local time for June

[illegible]

7.2

[illegible]

**B-50 Percent cloud cover for 04:00 local time for July**

[illegible]

**B-51 Percent cloud cover for 07:00 local time for July**

[illegible]

**B-52 Percent cloud cover for 10:00 local time for July**





[illegible]

**B-58 Percent cloud cover for 04:00 local time for August**







[illegible]

79

[illegible]

**B-64 Percent cloud cover for 22:00 local time for August**









**B-73 Percent cloud cover for 01:00 local time for Oct.**

**B-74 Percent cloud cover for 04:00 local time for Oct.**

















**B-89 Percent cloud cover for 01:00 local time for Dec.**

**B-90** Percent cloud cover for 04:00 local time for Dec.









Appendix C

Computer Program for albedo: AVALB

## AVALB

```

1      REAL LAMBDA,MS
2      DIMENSION A(12,36,18),C(12,36,18),D(12,36,18),NCR(36,18),
3      1 PC(8,29,12),RA(29),ND(12,36,18),AE(12,18),E(12,36,18),
3.2    2 IE(12,36,18),AEV(12,18),DEV(12,18)
4      DATA A/7760*0.0/,NCR/648*0/,PC/2784*0.0/,AEV/216*0.0/,DEV/216*0.0/
5      DATA RA/.625,.425,6*.6,4*.85,2*1.,.92,2*.85,2*.78,.85,
6      1 1.0,.82,.85,4*1.,2*.78/
6.5    READ(10,100) (((A(I,J,K),I=1,12),J=1,36),K=1,18)
8      READ(0,99) ((NCR(J,K),J=1,36),K=1,18)
9      READ(15,98) (((PC(LT,NT,N),LT=1,8),NT=1,29),N=1,12)
11.05  3 DO 4 I=1,12
11.1    DO 4 J=1,36
11.15   DO 4 K=1,18
11.2    C(I,J,K)=0.0
11.25   ND(I,J,K)=0
11.3    D(I,J,K)=0.0
11.35   IE(I,J,K)=0
11.4    E(I,J,K)=0.0
11.45  4 CONTINUE
12     NALB=0
13     VALB=0
14     VSPC=0
14.2    WRITE(6,97)
14.4    READ(5,101) I,N,NI,GLCLC
15     DO 20 LM=1,8
16     SSLON=(LM-1)*45.
17     SPC=0
18     SUM=0.
19     IF(N.EQ.1) DELTAS=-20.08
20     IF(N.EQ.2) DELTAS=-10.83
21     IF(N.EQ.3) DELTAS=-00.08
22     IF(N.EQ.4) DELTAS= 11.58
23     IF(N.EQ.5) DELTAS= 20.03
24     IF(N.EQ.6) DELTAS= 23.45
25     IF(N.EQ.7) DELTAS= 20.63
26     IF(N.EQ.8) DELTAS= 12.38
27     IF(N.EQ.9) DELTAS=  1.02
28     IF(N.EQ.10) DELTAS=-11.42
29     IF(N.EQ.11) DELTAS=-19.75
30     IF(N.EQ.12) DELTAS=-23.43
31     DO 10 L=1,18
32     THETA=5.*(L-0.5)
33     MS=0.7213-2.180E-09*THETA**4-4.941E-13*THETA**6
34     AS=0.0483+1.087E-05*THETA**2-2.219E-09*THETA**4+6.776E-13
35     1 *THETA**6
36     DO 10 M=1,72
37     ALPHA=5.*(M-.5)
38     TH=THETA/57.29577
39     AL=ALPHA/57.29577
40     DEL=DELTAS/57.29577
41     B=ARSIN(SIN(DEL)*COS(TH)+COS(DEL)*SIN(TH)*COS(AL))
42     BETA=57.29578*B

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43      EPS1=SIN(AL)*SIN(TH)/COS(B)
43.2    EPS2=(COS(TH)-SIN(DEL)*SIN(B))/(COS(DEL)*COS(B))
43.4    HS=ATAN2(EPS1, EPS2)
44      HOURS=57.29578*HS
45      LAMBDA=SSLON-HOURS
46      IF(LAMBDA.GT.360.) LAMBDA=LAMBDA-360.
47      IF(LAMBDA.LT.0) LAMBDA=360.+LAMBDA
48      K=IFIX(9.999999-BETA/10.)
49      J=IFIX(1.000001+LAMBDA/10.)
50      NT=NCR(J,K)
51      TLS=12.+HOURS/15.
53      IF(TLS.GT.23.5.OR.TLS.LT.2.5) LT=1
54      IF(TLS.GE.2.5.AND.TLS.LT.5.5) LT=2
55      IF(TLS.GE.5.5.AND.TLS.LT.8.5) LT=3
56      IF(TLS.GE.8.5.AND.TLS.LT.11.5) LT=4
57      IF(TLS.GE.11.5.AND.TLS.LT.14.5) LT=5
58      IF(TLS.GE.14.5.AND.TLS.LT.17.5) LT=6
59      IF(TLS.GE.17.5.AND.TLS.LT.20.5) LT=7
60      IF(TLS.GE.20.5.AND.TLS.LT.23.5) LT=8
60.1    IF(K.LT.14.OR.K.GT.15.AND.A(I,J,K).GT.31.) GO TO 8
60.2    IF(K.EQ.3.AND.A(I,J,K).GT.21.) GO TO 8
60.3    IF(K.EQ.3.AND.A(I,J,K).GT.14.) GO TO 5
60.4    IF(K.EQ.4.AND.J.NE.2.OR.J.NE.3.OR.J.NE.4.OR.J.NE.5.OR.J.NE.14
60.5    1 .OR.J.NE.15.OR.J.NE.16.OR.J.NE.17.OR.J.NE.18.OR.J.NE.19.OR.
60.6    2 J.NE.20.OR.J.NE.21.OR.J.NE.22) GO TO 5
60.7    IF(K.EQ.5.AND.J.NE.2.OR.J.NE.3.OR.J.NE.4.OR.J.NE.5.OR.J.NE.6
60.8    1 .OR.J.NE.14.OR.J.NE.15.OR.J.NE.16.OR.J.NE.17.OR.J.NE.18.OR.
60.9    2 J.NE.19.OR.J.NE.20) GO TO 5
61      IF(K.EQ.6.AND.A(I,J,K).GT.9.) GO TO 5
61.1    IF(K.EQ.7.AND.A(I,J,K).GT.8.) GO TO 5
61.2    IF(K.EQ.8.AND.A(I,J,K).GT.8.) GO TO 5
61.3    IF(K.EQ.9.AND.A(I,J,K).GT.7.) GO TO 5
61.4    IF(K.EQ.10.AND.A(I,J,K).GT.7.) GO TO 5
61.5    IF(K.EQ.11.AND.A(I,J,K).GT.7.) GO TO 5
61.6    IF(K.EQ.12.AND.A(I,J,K).GT.8.) GO TO 5
61.7    IF(K.EQ.13.AND.A(I,J,K).GT.9.) GO TO 5
61.8    IF(K.EQ.14.AND.I.EQ.6.OR.I.EQ.7) GO TO 5
63      C(I,J,K)=(A(I,J,K)*(0.03+.630/(1+((1.47-TH)/.15)**2)))/.1065
64      1 *MS+AS)*(1-PC(LT,NT,N)*GLCLC/60)+79.7*(1-.176*COS(TH))
65      2 *PC(LT,NT,N)*RA(NT)*GLCLC/60
66      GO TO 9
67      5 C(I,J,K)=(A(I,J,K)*.458*(1-COS(TH)*ALOG(1+1/COS(TH)))/.1874
68      1 *MS+AS)*(1-PC(LT,NT,N)*GLCLC/60)+79.7*(1-.176*COS(TH))
69      2 *PC(LT,NT,N)*RA(NT)*GLCLC/60
70      GO TO 9
71      8 C(I,J,K)=(A(I,J,K)*.797*(1-.176*COS(TH)))/.7035
72      1 *MS+AS)*(1-PC(LT,NT,N)*GLCLC/60)+79.7*(1-.176*COS(TH))
73      2 *PC(LT,NT,N)*RA(NT)*GLCLC/60
74      9 CONTINUE
74.2    D(I,J,K)=D(I,J,K)+C(I,J,K)
74.4    ND(I,J,K)=ND(I,J,K)+1
75      SPC=SPC+PC(LT,NT,N)*SIN(TH)
76      SUM=SUM+C(I,J,K)*SIN(TH)*COS(TH)
76.05   IF(NI.EQ.1) GO TO 10

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76.2      WRITE(6,95) L,M,BETA,LAMBDA,K,J,TLN,LT,NT,A(I,J,K),C(I,J,K),
76.4      1 PC(LT,NT,N),ND(I,J,K)
76.5      10 CONTINUE
77        SSPC=SPC*.001212034*GLCLC/60
78        ALB=SUM*.002424068
79        IF(NI.EQ.0) GO TO 19
80        WRITE(6,102) I,DELTAS,SSLON,ALB,SSPC
81        19 NALB=NALB+1
82        VSPC=VSPC+SSPC
83        20 VALB=VALB+ALB
84        AVALB=VALB/NALB
85        AVPC=VSPC/NALB
86        WRITE(6,103) AVALB,AVPC
86.1      DO 50 K=1,18
86.2      DO 50 J=1,36
86.3      IF(D(I,J,K).EQ.0.) GO TO 40
86.4      E(I,J,K)=D(I,J,K)/ND(I,J,K)
86.41     GO TO 50
86.42     40 E(I,J,K)=D(I,J,K)
86.422    50 IE(I,J,K)=E(I,J,K)
86.426    IF(NI.EQ.1) GO TO 60
86.44     WRITE(6,93) ((IE(I,J,K),J=1,36),K=1,18)
86.45     WRITE(6,93) ((ND(I,J,K),J=1,36),K=1,18)
86.48     60 DO 80 K=1,18
86.53     S=0.
86.54     NE=0
86.58     DO 70 J=1,36
86.6      IF(E(I,J,K).NE.0.) NE=NE+1
86.63     70 S=S+E(I,J,K)
86.65     IF(NE.EQ.0) GO TO 79
86.68     AE(I,K)=S/NE
86.681    GO TO 80
86.682    79 AE(I,K)=0.
86.685    80 CONTINUE
86.7      WRITE(6,104) (AE(I,K),K=1,18)
86.702    IF(I.NE.12) GO TO 90
86.705    WRITE(6,111) ((AE(I,K),I=1,12),K=1,18)
86.706    READ(19,112)((AEV(I,K),I=1,12),K=1,18)
86.707    DO 89 K=1,18
86.708    DO 89 I=1,12
86.709    89 DEV(I,K)=AEV(I,K)-AE(I,K)
86.71     WRITE(6,111)((DEV(I,K),I=1,12),K=1,18)
86.711    90 CONTINUE
86.72     93 FORMAT('0',36I3)
86.8      95 FORMAT(2I3,2F7.2,2I3,F7.2,2I3,3F7.2,I3)
87        97 FORMAT('0 ENTER I,N,NI,GLCLC')
88        98 FORMAT(8F4.2)
89        99 FORMAT(12I3)
90        100 FORMAT(12F6.2)
91        101 FORMAT(3I2,F4.1 )
92        102 FORMAT(2X,'I=',I2,2X,'DELTAS=',F6.2,2X,'SSLON=',F6.2,2X,
93        1-'ALBEDO=',F7.2,' PC=',F4.2)
94        103 FORMAT('0ALB=',F6.2,' PC=',F6.3/)
94.2      104 FORMAT(9F6.1/9F6.1)

```

```
94.3      105 FORMAT ('0',36F3.0)
94.4      106 FORMAT('0',36I3)
94.5      107 FORMAT('0',(8F6.2))
94.7      110 FORMAT('ONT=',I2,' AVPC=',F5.2)
94.8      111 FORMAT('1',(T3,12F6.1))
94.85     112 FORMAT(12F6.1)
95        GO TO 3
96        999 STOP
97        END
END OF FILE
```

Appendix D

Computer Program for Satellite Orbits

and

Latitude-Longitude Sampling for Three Satellite

System for each hour of the day 0100 to 2400



## \*LIST ORBITS

```

> 1 REAL LAMBDA,LAM,L,LAMBDO
> 2 DIMENSION ND(24,36,18),NSUM(24,18)
> 3 DATA ND/15552*0/,NSUM/432*0/
> 4 11 WRITE(6,89)
> 5 READ(5,90) H,OI,LAMBDO,NO
> 6 OIR=OI/57.29578
> 7 P=1.661E-4*(6370.+H)**1.5
> 8 OA=P/1440*(1+(0.9856+9.97*(6370/(6370+H))**3.5
> 9 1 *COS(OIR))/360.)
> 10 WRITE(6,101) P,OA
> 11 DO 10 IT=1,43200
> 12 SSLON=IT/4
> 13 17 IF(SSLON.GT.360.) GO TO 18
> 14 GO TO 19
> 15 18 SSLON=SSLON-360.
> 16 GO TO 17
> 17 19 L=360.*IT/(P*57.29578)
> 18 44 B=ARSIN(SIN(3.1415926-OIR)*SIN(L))
> 19 BETA=57.29578*B
> 20 EPS1=COS(3.1415926-OIR)*SIN(L)
> 21 EPS2=COS(L)
> 22 LAM=ATAN2(EPS1,EPS2)+OA*L
> 23 LAMBDA=57.29578*LAM+LAMBDO
> 24 55 IF(LAMBDA.GT.360.) GO TO 66
> 25 IF(LAMBDA.LT.0.) GO TO 65
> 26 GO TO 77
> 27 65 LAMBDA=LAMBDA+360
> 28 GO TO 55
> 29 66 LAMBDA=LAMBDA-360.
> 30 GO TO 55
> 31 77 HOURS=LAMBDA-SSLON
> 32 IF(HOURS.GT.180.) HOURS=HOURS-360.
> 33 IF(HOURS.LT.(-180.)) HOURS=HOURS+360.
> 34 K=IFIX(9.999999-BETA/10.)
> 35 J=IFIX(1.000001+LAMBDA/10.)
> 36 TLS=12.-HOURS/15
> 36.2 LT=IFIX(TLS)
> 36.4 GO TO 9
> 37 7 IF(TLS.GT.23.5.OR.TLS.LT.2.5) LT=1
> 38 IF(TLS.GE.2.5.AND.TLS.LT.5.5) LT=2
> 39 IF(TLS.GE.5.5.AND.TLS.LT.8.5) LT=3
> 40 IF(TLS.GE.8.5.AND.TLS.LT.11.5) LT=4
> 41 IF(TLS.GE.11.5.AND.TLS.LT.14.5) LT=5
> 42 IF(TLS.GE.14.5.AND.TLS.LT.17.5) LT=6
> 43 IF(TLS.GE.17.5.AND.TLS.LT.20.5) LT=7
> 44 IF(TLS.GE.20.5.AND.TLS.LT.23.5) LT=8
> 45 9 IF(NO.EQ.1) GO TO 10
> 46 WRITE(6,100) SSLON,L,BETA,LAMBDA,HOURS,TLS,K,J,LT
> 47 10 ND(LT,J,K)=ND(LT,J,K)+1
> 48 DO 20 LT=1,24
> 49 20 WRITE(6,102) ((ND(LT,J,K),J=1,36),K=1,18)
> 49.1 21 DO 30 LT=1,24
> 49.2 DO 30 K=1,18
> 49.3 NSUM(LT,K)=0

```

```

> 49.4      DO 30 J=1,36
> 49.5      30 NSUM(LT,K)=NSUM(LT,K)+ND(LT,J,K)
> 49.6      WRITE(6,103) ((NSUM(LT,K),LT=1,24),K=1,18)
> 50        GO TO 11
> 51        89 FORMAT('OENTER H,I,LAMBDO,NO')
> 52        90 FORMAT(3F7.2,I2)
> 53        100 FORMAT(' ',6F7.2,3I3)
> 54        101 FORMAT(2F8.3)
> 55        102 FORMAT('2',(' ',T3,36I3))
> 55.2      103 FORMAT('2',(' ',T2,24I4))
> 56        999 STOP
> 57        END
#END OF FILE
#

```

NOTE: Instructions 37-44 not used at present.

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
8	7	8	7	7	9	7	7	7	8	9	8	9	7	7	8	7	8	9	7	8	8	8	9	6	8	8	8	8	7	8	7	7	8	8	8	1
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	
2	3	1	5	0	3	2	2	4	0	4	2	2	3	0	3	0	4	0	1	2	0	3	0	2	2	1	3	0	4	1	1	3	0	4	0	9
4	4	3	4	2	5	4	3	5	4	4	3	4	6	4	4	2	3	3	3	5	3	4	3	4	4	2	5	2	5	3	2	4	3	4	5	10
4	3	4	3	4	5	3	4	3	4	4	4	5	2	3	4	2	5	1	5	4	4	4	3	5	3	5	4	3	4	2	4	5	5	5	3	11
5	1	5	4	4	4	3	4	6	5	4	5	4	3	4	3	4	6	5	4	5	3	4	5	5	3	3	3	4	4	4	5	4	4	4	12	
5	7	5	6	5	6	6	6	7	4	7	4	5	8	5	7	5	7	6	8	7	7	10	5	8	6	7	6	5	9	6	7	5	5	9	7	13
11	9	11	9	9	10	9	10	10	9	10	8	9	9	8	10	10	9	10	8	10	8	10	10	9	9	11	9	10	11	9	11	9	9	9	14	
21	19	20	20	22	18	17	20	17	21	20	21	20	18	20	18	18	18	21	20	19	19	19	19	18	19	18	20	21	18	20	21	22	21	18	20	15
5	6	4	5	6	4	5	6	4	5	5	4	5	6	3	5	5	4	6	4	4	6	4	4	3	5	5	5	5	5	5	4	5	5	4	16	
37	37	34	38	35	36	36	33	41	33	36	39	31	39	37	31	38	37	33	29	33	36	37	35	38	33	35	39	34	36	38	34	36	36	34	17	
8	11	9	9	11	8	11	11	8	12	10	10	12	10	11	11	10	12	9	9	11	9	10	10	10	11	10	11	10	11	10	11	12	10	11	12	18
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	

0100

104

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
8	8	7	8	7	8	9	6	8	7	9	7	9	8	9	8	8	8	7	8	7	8	7	7	9	8	9	8	7	9	8	8	6	8	7	8	1
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3	4	3	2	5	2	5	5	2	4	3	4	4	4	3	2	5	0	3	3	3	5	1	5	2	3	4	2	4	2	4	3	3	4	3	8	
4	4	4	5	5	3	4	3	3	5	5	5	4	3	4	4	4	3	5	3	4	4	3	5	4	5	5	4	4	1	4	6	5	4	9		
12	15	11	12	12	11	12	12	15	9	12	15	9	12	13	11	13	14	10	13	12	10	14	11	12	13	10	12	13	14	12	12	12	11	14	12	10
34	42	35	37	29	36	42	37	36	39	36	38	36	38	41	36	39	36	36	40	36	37	38	33	42	34	37	42	32	42	35	36	42	31	40	39	11
36	39	37	40	38	36	38	36	36	29	35	39	39	34	40	36	38	42	34	42	35	36	42	34	39	38	38	42	35	38	37	35	41	36	36	37	12
36	41	37	37	42	32	40	39	35	44	31	38	40	35	39	40	34	42	36	36	36	37	40	37	38	39	35	42	38	36	41	37	37	39	35	41	13
35	42	42	37	45	37	41	43	37	42	42	41	39	40	38	43	43	39	44	39	43	41	42	42	37	49	34	41	44	33	48	37	42	42	37	47	14
54	50	57	51	53	53	53	55	53	54	52	53	60	49	53	57	49	55	56	51	60	53	53	54	49	56	54	52	58	50	55	52	50	56	51	53	15
31	28	32	28	29	34	25	31	31	25	35	29	27	32	28	29	32	27	32	30	29	31	29	33	30	30	32	27	31	30	29	32	29	31	28	30	16
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0200

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
	8	10	7	8	9	7	8	9	6	10	8	7	8	9	8	8	8	9	7	10	8	7	10	9	6	10	6	9	9	7	9	10	7	10	8	1	
	1	1	0	2	1	0	1	1	0	1	0	1	1	0	1	1	0	2	1	1	1	1	1	0	0	1	0	0	1	2	0	2	1	0	1	0	2
	0	1	0	0	0	0	1	1	0	1	1	0	1	2	0	2	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	3	
	31	33	35	31	37	33	32	36	32	34	34	33	27	33	33	35	32	36	33	34	36	31	37	33	32	39	30	34	36	30	37	32	32	35	31	35	4
	37	33	35	34	35	34	33	39	29	36	39	29	38	36	30	38	33	32	37	31	36	34	32	39	31	35	36	32	38	33	34	37	33	36	33	34	5
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	31	30	28	35	25	29	33	25	32	31	27	32	27	26	32	27	32	31	27	32	28	29	30	29	31	29	30	30	29	31	29	31	30	28	32	25	9
	4	5	2	4	2	4	5	2	5	4	4	3	4	5	4	5	3	3	4	4	4	5	5	4	4	4	2	4	3	5	5	2	4	4	4	10	
	4	3	4	3	4	5	4	5	3	4	4	3	5	3	3	4	2	4	3	5	5	4	4	1	4	4	4	5	3	3	4	4	5	5	3	11	
	5	4	5	3	4	4	4	5	3	6	5	4	4	3	5	4	5	5	6	3	4	4	5	6	4	3	5	3	4	4	4	6	4	4	3	12	
	4	5	5	6	4	6	5	3	5	4	5	5	4	5	4	6	5	4	5	4	6	4	4	5	4	6	4	5	6	4	4	4	5	4	5	13	
	19	16	20	15	15	20	14	18	19	15	19	14	18	17	15	19	18	19	16	20	17	16	18	16	19	16	19	18	16	21	13	19	14	18	19	18	14
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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	

0300

K

105

J	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
	27	23	24	25	20	27	23	20	26	22	26	27	23	27	25	23	26	24	24	24	23	24	23	25	22	22	24	23	23	25	24	25	23	27	25	21	2
	35	37	33	38	36	33	38	34	36	35	34	37	36	33	37	33	36	36	33	38	34	36	37	33	38	32	37	38	31	41	34	32	38	33	36	35	3
	2	1	1	1	1	0	1	1	1	1	0	2	0	0	2	0	0	2	0	0	2	0	0	1	0	1	1	1	1	0	2	1	1	2	1	1	4
	2	5	3	2	5	3	5	3	5	3	4	3	2	3	2	4	2	2	4	2	3	3	2	3	2	4	2	5	3	1	3	2	3	4	4	5	
	5	5	5	5	3	6	4	6	5	4	6	3	5	5	5	5	5	6	4	5	4	6	4	5	4	4	5	5	6	4	5	5	3	6	3	6	
	4	5	5	5	4	3	3	4	5	5	5	3	5	4	4	4	3	6	3	4	2	4	6	5	5	4	4	3	5	3	4	5	4	5	4	7	
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	5	4	6	4	5	5	4	6	4	6	4	5	6	3	6	4	5	6	4	6	4	5	5	5	4	4	6	4	5	5	4	5	5	5	4	13	
	13	15	10	13	13	13	17	12	15	13	14	11	15	14	15	15	16	15	13	15	16	11	14	16	13	16	12	16	14	15	11	15	15	14	14	14	
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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18		

0400

K

	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
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40	40	42	40	42	41	39	43	39	42	40	41	41	41	39	43	40	41	42	40	42	39	43	40	38	45	37	41	41	38	44	40	40	42	39	43	2	
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0900

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16. Abstract <p>A time variable model of Earth's albedo has been prepared for use in climate studies and as an aid to the interpretation of satellite Earth radiation budget data. The Fortran computer program is assembled in modular form so that improvements can be made to any module independently of the rest. Features of the model include: a 10° latitude-10° longitude grid for numerical integration, surface albedo specified at 1 month intervals, calculation of zenith angle effect for surface albedo and of the additional effect of the atmosphere on the albedo. Percent cloud cover is specified for 29 different climatological cloud type regions at 8 times of the day for 12 months of the year. Cloud albedos have been specified for each of the cloud climatological types. Diurnal and monthly variations of this model are described and results are compared with the model of Ellis and Vonder Haar, which is based on satellite measurements.</p> <p>A computer program has also been written for use in studying the sampling effects in satellite radiation budget measurements. An example of the results of calculations with this program are compared with a previous study of the sampling effects. This program for satellite orbit characteristics is to be combined with the time-variable albedo model for further study of the sampling problem.</p>					
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